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Factors Affecting the Demand for Ethanol as a Motor Fuel

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ABSTRACT

This report examines factors affecting the demand for ethanol as a motor fuel, both as a blendstock or as a neat fuel. As a blendstock, the demand for ethanol is determined by its value to the refiner; as a neat fuel, the demand is determined by its competitiveness with other fuels. The factors considered in this report include the chemical and physical properties of ethanol, gasoline prices, federal and state tax incentives, federal and state oxygen-content and emission requirements, greenhouse gas (GHG) benefits, and infrastructure barriers.

Ethanol used in low-level blends is valuable because of its oxygenate and octane-enhancement properties. In optimized blending, the value of ethanol is further increased because it can displace some of the more costly components of gasoline. On the down side, low-level ethanol blends have an increased Reid vapor pressure (RVP) and may cause a slight rise in nitrous oxide emissions. The Oak Ridge National Laboratory Refinery Yield Model (ORNL-RYM) was used to determine the optimal value of ethanol to the refinery and to derive an ethanol demand curve.

The value of neat ethanol relative to gasoline is computed by calculating the cost of each fuel to drive the same distance. The penetration of neat ethanol into the marketplace is dependent on additional infrastructure development, such as vehicle and retail fueling availability, and the report discusses these requirements. The paper also examines infrastructure issues that affect ethanol used in both blends and as a neat fuel, including problems associated with shipping ethanol in common-carrier pipelines and additional storage and handling procedures needed to guard against water incursion.

The report reviews the current federal and state tax incentives for ethanol, including the federal excise tax exemptions and income tax credits, and characterizes the actual cost of the incentives to the government. The ethanol incentives have both an energy and a farming constituency, and the relationship to farm support programs is discussed. The report also discusses the federal incentives for alternative fueled vehicles (AFVs), including the income tax deductions and CAFE credits.

Because cellulosic ethanol has the greatest GHG benefits of all the alternative fuels identified in EPACT and the CAAA, it could play an important role in helping the nation reduce anthropogenic carbon emissions. GHG benefits are currently an externality, but government policies may be introduced to promote reductions in carbon emissions. The report examines the range of mechanisms by which the GHG benefits could be internalized.

EXECUTIVE SUMMARY

Purpose and Overview

The purpose of this report is to review issues relating to ethanol demand as a motor fuel. The results reported here are intended to support the U.S. Department of Energy's (DOE) Analysis of Market Potential and Benefits of Cellulosic Ethanol, spearheaded by the Office of Fuels Development (OFD). The cellulosic ethanol program is one part of a national energy strategy developed in response to the mandates and goals of the Energy Policy Act of 1992 (EPACT) and other federal legislation. These acts directed DOE to promote the development of both renewable, alternative transportation fuels that could provide environmental benefits and help reduce the nation's dependence on imported petroleum.

Ethanol can be used as a blendstock or as a neat fuel, and the demand for ethanol in both these fuel types is examined. Currently, almost all fuel ethanol in the United States is used as a blendstock in low-level ethanol blends. The economic and market analyses for blendstock and neat fuels are quite different and are discussed separately.

Legislation

Several key legislative initiatives affect the demand for ethanol. The most important of these are the Federal excise tax exemptions and income tax credits, which are currently equivalent to 54 cents per gallon of ethanol. Some states, primarily the ethanol producing states in the Midwest, provide ethanol tax incentives ranging from 10 to 20 cents per gallon. The tax incentives are essential to the current corn-based ethanol industry and will also be indispensable to the evolving cellulosic ethanol industry. Stability of the tax incentives will play a major role in ethanol plant investment decisions.

The cost of the tax incentives to the government can be divided into two categories: (1) the impact on tax revenues from a fiscal tax policy point of view which assumes GDP remains fixed and (2) the taxes on additional taxable income generated from producing ethanol, i.e., from an increase in GDP.

With respect to the first category, the nominal ethanol incentives, i.e., for the Federal excise tax exemption and income tax credit, overstates the change in total government tax receipts or the actual cost of the incentive to the government for two reasons. First, IRS regulations effectively treat the ethanol incentive as gross revenue, which is taxed at the taxpayer's marginal tax.   Second, liquid motor fuel taxes are assessed volumetrically, but ethanol has only about two-thirds of the energy content of gasoline for an equal volume, or about 50 percent more ethanol compared to gasoline is required to travel a given distance. A recent analysis of the ethanol tax incentives estimated that the actual cost to the Federal government of the 54 cent per gallon ethanol tax incentives is 34 cents per gallon[1]. The

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[1]David Andress, Ethanol Tax Incentives and Issues, David Andress & Associates, Inc., April 1998

study also estimated that the actual decrease to federal and state tax revenues due to the combined federal and state tax incentives was about 50 percent of the incentive level.

The second category deals how the ethanol incentives increase GDP. Several factors are involved here. The ethanol industry creates additional jobs not only in the ethanol industry itself but also from the economic multiplier effect. Ethanol also displaces some foreign source oil and/or methyl tertiary butyl ether (MTBE), which will add to domestic taxable receipts and improve the nation's trade balance. Indirectly, ethanol may lower the price of oil or MTBE through decreased demand for these products. Ethanol will increase the demand for agricultural products and consequently increase the prices farmers receive.

The other major Federal laws that have an impact on ethanol usage are the Energy Policy Act of 1992 (EPACT) and the Clean Air Act Amendments (CAAA). EPACT established requirements for alternative fueled vehicles (AFVs) and set petroleum reduction targets. Neat ethanol is one of the alternative fuels recognized by EPACT and will compete with other alternative fuels in meeting EPACT goals. The CAAA set requirements for clean alternative fuels, mandated the use of oxygenated fuels in carbon monoxide non-attainment areas, and established guideline levels of criteria pollutants emitted from vehicular fuels. Most oxygen requirements today are satisfied with ethanol and MTBE, which compete primarily on price. The CAAA also grants a one-psi RVP waiver for conventional gasoline with 10 percent ethanol. The RVP waiver does not apply to ethanol used in reformulated gasoline (RFG), and this hinders its use in RFG.

Low-Level Blends

The value of ethanol used in low-level blends is quite complex. As an octane enhancer, it displaces the need for other highly toxic and potentially carcinogenic octane enhancers such as benzene, toluene, and xylene (BTX). As an oxygenate, it reduces tailpipe carbon monoxide emissions. Its inclusion as a gasoline blendstock reduces tailpipe emission levels of some of the criteria pollutants regulated by EPA. In addition to BTX, ethanol can displace other costly components of gasoline when blended with optimized subgrade gasoline stocks. On the down side, low-level ethanol blends have an increased Reid vapor pressure (RVP), which is associated with increased evaporative emissions, and may cause a slight rise in nitrous oxide emissions.

Scientists at Oak Ridge National Laboratory (ORNL) use the Refinery Yield Model (ORNL-RYM) to determine the value of ethanol to the refinery[2]. ORNL-RYM, a very detailed linear-programming representation of regional petroleum refining, determines the minimum refinery cost for a given set of premises and constraints, such as the EPA pollutant emission requirements. By systematically varying ethanol prices, ORNL scientists developed a demand curve for ethanol used in low-level blends that

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[2]Hadder, G.R., *Draft Ethanol Demand in United States Gasoline Production*, ORNL-6926, Oak Ridge National Laboratory, November 1998

Figure 1. Ethanol Demand Curves for U.S. Gasoline Production and Finishing in Years 2000 to 2025 - Reference Conditions
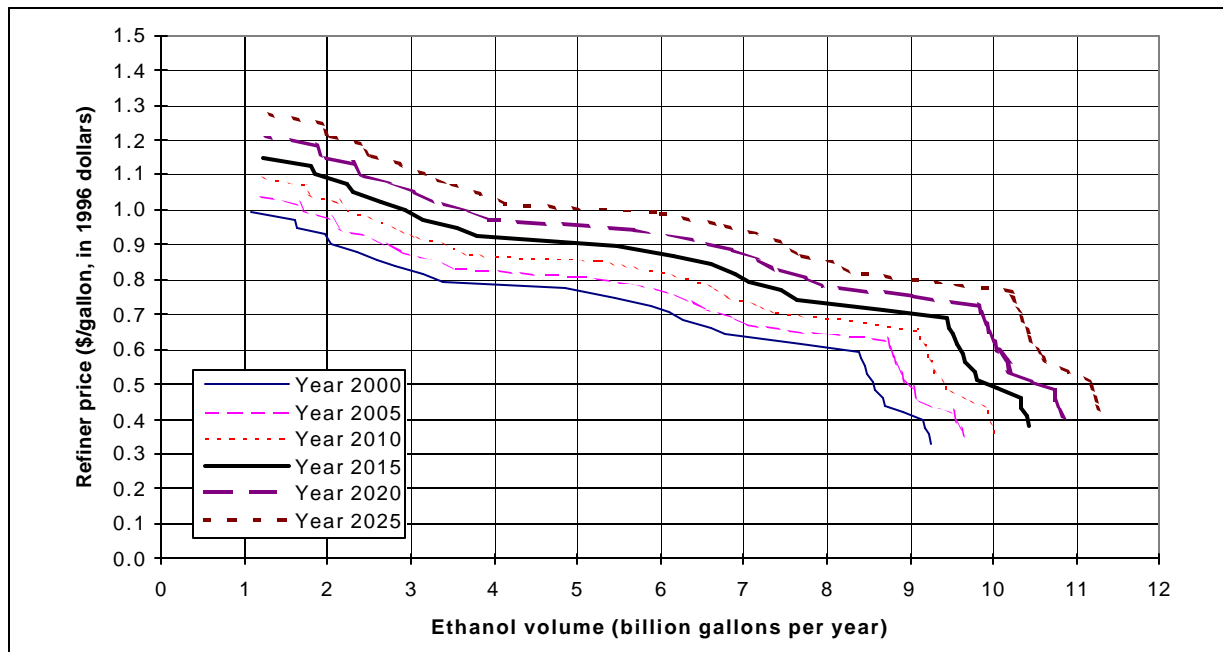
provides the quantity of ethanol demanded by the refinery at each price level. The analysis included ethanol used in ethyl tertiary butyl ether (ETBE). Figure 1 displays ethanol demand curves for the years 2000 through 2025 in five year increments for the reference conditions in DOE / Energy Information Administration's (EIA) annual energy forecast.

A major finding of the ORNL analysis was that the ethanol demand was higher for conventional gasoline than for reformulated gasoline (RFG), because of RVP advantages for ethanol blended with conventional gasoline. Specifically, conventional gasoline containing 10 percent ethanol is granted a one pound per square inch (psi) RVP waiver, which corresponds roughly to the RVP increase of a 10 percent ethanol blend. Because of concerns of ozone formation from evaporative emissions of volatile organic compounds (VOC), EPA set VOC limits for summer RFG lower than those of conventional gasoline. RFG/ethanol blends are not granted an volatility waiver.

ORNL also examined the volume of ethanol demanded at each price level for several sensitivity cases, including higher oil prices and alternative EPA emission regulations. Sensitivity cases suggest that ethanol demand could increase with specification changes for (lower) sulfur content, (higher) oxygen content, (higher) VOC emissions, and (higher) octane number. Significant increases in ethanol demand could occur for reduced sulfur gasoline and higher octane requirements. A VOC waiver for ethanol used in RFG increases ethanol's attractiveness. Increasing the allowable oxygen limit in gasoline could increase the demand for ethanol by up to 16 percent. Accounting for toxic air pollutants associated

with methyl tertiary butyl ether MTBE in EPA's Complex Model has virtually no effect on ethanol demand.

Neat Fuels

The economics of ethanol used as a neat fuel are, in some ways, simpler than the economics of ethanol used as a blendstock. The value of neat ethanol versus the value of gasoline can be easily computed by calculating the cost of each fuel to drive the same distance. Since ethanol has only about two-thirds of the BTU content of gasoline on a volume basis, a larger quantity of ethanol is required to travel a given distance. Ethanol, however, can be more efficiently converted to energy than gasoline. The BTU efficiency advantage for ethanol has been estimated at 5 to 12 percent, depending on the characteristics of the engine used.

The analytic results presented here show that ethanol is more valuable as a blendstock than as a neat fuel. Neat fuels will not be competitive until the price of ethanol, after any tax incentives, is about 70 to 85 percent the price of gasoline on a volume basis. At that point, the demand for low-level ethanol blends is fairly saturated. In 2010, for example, the price of ethanol must be between 60 and 70 cents (1996 dollars) per gallon, depending on whether neat ethanol fuels are positioned to compete with regular or premium gasoline. Ethanol's high octane content presents an opportunity to compete ethanol with premium gasoline in the marketplace.

Some niche markets for neat ethanol will develop because of Federal and state laws mandating the use of alternative fuels in certain fleets. However, any analysis of significant market penetration of neat ethanol fuel must include the question of infrastructure availability. As opposed to low-level ethanol blends, which are interchangeable with gasoline, neat fuels entail a transition to an alternative fuel type. Currently, the distribution infrastructure for neat ethanol fuels is very limited, and neat ethanol is only available in a handful of refueling outlets. Several automobile manufactures offer flexible-fueled vehicles (FFV) cars that use either gasoline or neat ethanol fuels. The present selection is limited and the vehicles have are optimized for neat ethanol fuels. However, as the experience with ethanol fuels in Brazil has shown, automobile manufacturers can easily increase their offering of ethanol capable vehicles, if consumer demand warranted it.

Transportation Logistics and Infrastructure Issues

Some transportation logistics and infrastructure barriers, primarily distribution and bulk storage, apply to ethanol used as a blendstock or as a neat fuel. Neat fuels require infrastructure additions for fuel dispensing, especially at the retail level and the availability of vehicles that can use neat ethanol. The major infrastructure issues are listed below:

      C   Ethanol plants have to be located near feedstock sources.
      C   Ethanol costs for transporting ethanol are more expensive than for gasoline. Thus,

ethanol plant proximity to the end user is important until an alternative distribution system, e.g., dedicated pipelines, is developed for ethanol.

C   A network of accessible retail filling stations capable of dispensing neat ethanol must be established.

C   Vehicles that can use neat ethanol must be readily available.

Ethanol's water solubility limits its ability to be transported in today's common carrier pipelines as water incursion often occurs in current operating environments. Water absorption by ethanol could cause phase separation in gasoline ethanol blends leading to logistic and driveability problems. Ether blends, such as ETBE, do not absorb water and are transported in common carrier pipelines in the same manner as unblended gasoline. However, the production of ETBE involves additional costs that must be offset by the economic benefits of its desirable properties, such as pipeline transportability and lower RVP blends.

Ethanol is widely used in Brazil both as a blending agent and as a neat fuel, showing that infrastructure barriers can be overcome. Unlike the U.S., Brazil does not have a large indigenous oil supply, and the Brazilian government adopted a national energy plan to promote ethanol usage. Brazilian ethanol comes primarily from sugar cane. A valuable lesson learned from the Brazilian experience was that the government had to adopt policies insuring an adequate supply of ethanol at reasonable prices. In doing so, the Brazilian government had to deal with both crop yield fluctuations and changing sugar prices on the world market.

Greenhouse Gases

Concern about of global warming, the so-called greenhouse gas (GHG) effect caused by the release of carbon from the combustion of fossil fuels, is currently a topic of enormous interest in the international community. The Kyoto conference established a set of goals for reducing anthropogenic carbon emissions. The U.S. is in the process of developing a strategy to meet airborne carbon reduction goals, and cellulosic-based alcohol fuels, because of their beneficial GHG properties, could play a prominent role here. Recent scientific studies have shown that there is a modest reduction in net carbon emissions from corn-based ethanol and a virtually total elimination of net carbon emissions from cellulosic-based ethanol. For example, an analysis done at Argonne National Laboratory for the year 2010 concluded that the reductions in GHG emissions for cellulosic ethanol relative to gasoline ranged from about 92 percent for herbaceous biomass to 120 percent for woody biomass[3]. The GHG benefits from ethanol were approximately the same whether the ethanol was used in gasohol (E10) or as a neat fuel (E85 and E95).

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[3]Michael Wang, Chris Saricks, Dan Santini, Fuel Cycle Energy and Greenhouse Gas Emission Effects of Ethanol, Argonne National Laboratory, September 4, 1998

As a rough estimate, ethanol reduces vehicular carbon emissions compared with the gasoline (on an energy equivalent basis) at the rate of 1.6 tonnes of carbon for each 1000 gallons of ethanol. Various studies have suggested that the value of a ton of carbon avoided is approximately $55. This translates into a GHG benefit of about 9 cents per gallon of ethanol.

At the current time, GHG benefits from cellulosic ethanol are strictly an externality. Neither the ethanol producer nor the ethanol user faces any economic or regulatory incentives related to GHG emissions. However, GHG benefits do influence government policy and funding decisions, such as allocation of R&D funds to improve renewable ethanol production technology and reduce costs. They may also play a role in determining ethanol and alternative vehicle tax incentives.

DOE has sponsored a number of studies to examine potential approaches for meeting carbon emission goals in the transportation sector. The studies considered various alternatives, such as enacting tax incentives, imposing carbon taxes, and establishing prescribed carbon release limits through a regulatory mechanism. The latter approach could be implemented via emissions trading program similar those used in the electrical generation industry or regulating GHG emissions similar to the current approach to reducing mobile criteria pollutant emissions. Since the GHG benefits of cellulosic ethanol are greater than those of other alternative fuels, the imposition of carbon-related taxes or tax incentives is more favorable to ethanol. Nevertheless, price and infrastructure development will ultimately determine the extent of ethanol penetration in the marketplace.

The Joint Implementation proposal introduced in the 1997 Kyoto Conference and advocated by the U.S., encompasses a partnership between a developed nation and developing host country for projects that reduce carbon emissions, such as renewable energy power plants, retrofits of existing plant and equipment, and forest management projects. The contributing developed country would obtain carbon reduction credits for contributing know-how, technology, and/or capital. Cellulosic ethanol can provide tremendous opportunities in this area. For resource-poor countries, cellulosic ethanol projects can reduce a developing country's dependence on imported oil and provide domestic economic growth. The partner country can reap the benefit of the GHG emissions credits. The opportunity for ethanol production in some developing countries may be even greater than in the U.S., because of high gasoline prices in many developing countries.

1. INTRODUCTION

Background

As the nineteenth century came to a close, small quantities of biomass-based alcohols were used both as a fuel source and for chemical feedstocks. Shortly thereafter, the discovery of abundant petroleum reserves and the development of large, efficient refineries ushered in an era of inexpensive oil and relegated alcohol fuels to a niche market. The U.S. enjoyed years of inexpensive gasoline and energy indulgence until the 1970s Arab oil embargo, which underscored the nation's vulnerability to supply disruptions and triggered steep increases in petroleum prices. In response to public outcries about energy security and stability, the federal government formulated a national energy strategy that emphasized the need to diversify the nation's energy sources and improve energy efficiency. Congress envisioned that domestic, renewable fuel sources would play a key role in meeting this goal and enacted special tax incentives to stimulate the production and use of biomass-derived ethanol.

By the mid 1980s, real oil prices had declined from their all-time highs and public concerns about energy supply disruptions eased. While the long-term need to develop petroleum replacement products remained, the near-term economic exigency for ethanol and other alternative fuel sources diminished. However, two developments created a renewed demand for alcohol-based fuels in the late eighties: (1) the banning of lead, a widely-used additive for increasing gasoline octane levels, and (2) the continuing deterioration in the nation's air quality from vehicular emissions. The properties of alcohol fuels and alcohol-based ethers make them ideal candidates for addressing both these problems.

The 1990 Clean Air Act Amendment (CAAA) recognized the role that the clean fuels could play in decreasing carbon-monoxide levels, improving air quality problems, and reducing ozone formation. The CAAA requires that a: gasoline sold in metropolitan areas with severe winter carbon monoxide problems to have a minimum oxygen content and (b) summer gasoline in serious and extreme ozone nonattainment areas to meet specified emissions requirements. Alcohol-based fuels provide oxygen and help reduce some vehicular toxic and particulate emissions.

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Purpose and Overview

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Ethanol can be used as a blendstock or as a neat fuel, and the demand for ethanol in both these fuel types is examined. Currently, almost all fuel ethanol in the United States is used as a blendstock in low-level ethanol blends. The economic and market analysis for blendstock and neat fuels are quite different and are discussed separately in Chapters 4 and 5.

The value of ethanol used in low-level blends is quite complex. As an octane enhancer, it displaces the need for other highly toxic and potentially carcinogenic octane enhancers such as benzene, toluene, and xylene (BTX). As an oxygenate, it reduces vehicular carbon monoxide emissions. Its inclusion as a gasoline blendstock reduces tailpipe emission levels of some of the criteria pollutants regulated by EPA. In addition to BTX, ethanol can displace other costly components of gasoline when blended with optimized subgrade gasoline stocks. On the down side, low-level ethanol blends have an increased Reid vapor pressure (RVP), which is associated with increased evaporative emissions, and may cause a slight rise in nitrous oxide emissions.

Scientists at Oak Ridge National Laboratory (ORNL) use the Refinery Yield Model (ORNL-RYM) to determine the value of ethanol to the refinery. RYM is a very detailed linear-programming representation of the refinery process that determines the minimum refinery cost for a given set of premises and constraints, such as EPA tailpipe emission requirements. By systematically varying ethanol prices, ORNL scientists developed a demand curve for ethanol used in low-level blends that provides the quantity of ethanol demanded by the refinery at each price level. ORNL also examined the volume of ethanol demanded at each price level for several sensitivity cases, including higher oil prices and alternative EPA emission regulations. A major finding of the ORNL analysis[4] was that the ethanol demand was higher for conventional gasoline than for reformulated gasoline (RFG), because conventional gasoline containing 10 percent ethanol is allowed to have a RVP that is 1 pound per square inch (psi) higher than the EPA ceiling for gasoline and other alcohol fuel mixes. Furthermore, RVP limits for summer RFG are lower than those of conventional gasoline in order to limit volatile organic compound (VOC) emissions that contribute to zone formation. RFG/ethanol blends are not granted the RVP waiver.

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[4]Hadder, G.R., *Draft Ethanol Demand in United States Gasoline Production*, ORNL-6926, Oak Ridge National Laboratory, November 1998

The ORNL analysis looked at the use of both ethanol and ethyl tertiary butyl ether (ETBE). ETBE is a chemical compound produced by reacting ethanol and isobutylene (a petroleum-derived by-product of the refining process). ETBE has several physical characteristics that make it a more desirable blendstock than ethanol: (1) low-level ETBE blends have reduced RVPs and (2) ETBE is less water soluble than ethanol. Because ethanol is highly water soluble, ethanol blends, unlike ETBE blends, cannot be shipped in existing gasoline pipelines without first purging them of water. This reduces transportation costs of ETBE blends relative to ethanol blends and eliminates the need for splash blending with a subgrade gasoline. However, the production of ETBE involves additional costs which must be offset by the economic benefits of its desirable properties.

EPA regulates the allowable oxygen content of gasoline. Currently, EPA imposes an oxygen content limit of 3.5 weight-percent for ethanol used in low-level gasoline blends and a 2.7 weight percent for ethers used in gasoline blends. This is roughly equivalent to a 10 percent ethanol content by volume for straight ethanol and a 7.7 percent ethanol content for ETBE.

In one sense, the economics of ethanol used as a neat fuel is simpler than the economics of ethanol used as a blendstock. The value of neat ethanol versus the value of gasoline can be easily computed by calculating the cost of each fuel to drive the same distance. Since ethanol has only about two-thirds of the BTU content of gasoline on a volume basis, a larger quantity of ethanol is required to travel a given distance. Ethanol, however, can be more efficiently converted to energy than gasoline. The BTU efficiency advantage for ethanol has been estimated at 5 to 12 percent, depending on the characteristics of the engine used.

Any analysis of ethanol fuels must include the all-important question of infrastructure availability, and this is especially critical for neat fuels. As opposed to low-level ethanol blends, which are interchangeable with gasoline, neat fuels entail a transition to an alternative fuel type. Currently, the distribution infrastructure for neat ethanol fuels is very limited – neat ethanol is only available in a handful of refueling outlets. Several automobile manufactures offer flexible-fueled vehicles (FFV) cars that use either gasoline or neat ethanol fuels. The present selection is limited and the vehicles have not been optimized for neat ethanol fuels. However, as the experience with ethanol fuels in Brazil has shown, automobile manufacturers can easily increase their offering of ethanol capable vehicles if consumer demand warranted it.

The analytic results presented here show that ethanol is more valuable as a blendstock than as a neat fuel. Neat fuels will not be competitive until the price of ethanol, after any tax incentives, is about 70 to 85 percent the price of gasoline on a volume basis. At that point, the demand for low-level ethanol blends is fairly saturated. The use of neat ethanol will be determined not only by a competitive price, but by infrastructure and transitional issues. However, some niche markets for neat ethanol will develop because of Federal and state laws mandating the use of alternative fuels in certain fleets.

Several key legislative initiatives affect the demand for ethanol. The most important of these are the Federal and state tax incentives. The Federal tax incentive is currently equivalent to 54 cents per gallon of ethanol. Some states, primarily the ethanol producing states in the Midwest, provide incentives ranging from 10 to 20 cents per gallon. The tax incentives are absolutely essential to the current corn-based ethanol industry and will also be indispensable to the evolving cellulosic ethanol industry. Stability of the tax incentives will play a major role in ethanol plant investment decisions.

The other major Federal laws that have an impact on ethanol usage are the Energy Policy Act of 1992 (EPACT) and the Clean Air Act Amendments (CAAA). EPACT established requirements for alternative fueled vehicles (AFVs) and set petroleum reduction targets. Neat ethanol is one of the alternative fuels recognized by EPACT and will compete with other alternative fuels in meeting EPACT goals. The CAAA set requirements for clean alternative fuels, mandated the use of oxygenated fuels in carbon monoxide non-attainment areas, and established guideline levels of criteria pollutants emitted from vehicular fuels. The two major oxygenates currently in use are ethanol and MTBE. They compete primarily on price. The CAAA also grants a one-psi RVP waiver for conventional gasoline with 10 percent ethanol. The RVP waiver does not apply to ethanol used in reformulated gasoline (RFG), and this hinders its use in RFG.

State laws may be beneficial or detrimental to ethanol usage. Several states have enacted legislation encouraging the use of ethanol such as requiring ethanol to be used in state motor vehicle fleets and establishing minimum statewide oxygen levels for gasoline. Other states have passed laws or instituted legislation restricting the use of ethanol, such as limiting oxygen levels or imposing reduced RVP limits. While reduced RVP limits do not technically eliminate the use of ethanol as a blendstock, they do put ethanol at a competitive disadvantage since refineries have to produce a lower RVP subgrade gasoline for ethanol blending.

2. LEGISLATION

Tax Incentives

Tax incentives are essential to spur the development of the cellulosic ethanol industry as they provide the economic bridge for pioneering plants. The federal incentives provide the lion's share of the combined Federal and state incentives, but the state incentives often provide the extra boost needed to make a new plant financially viable. The political motivations behind the tax incentives are diverse. On the Federal level, they currently combine both energy and agricultural objectives. In the future, reduction of carbon emissions could play an important role. On the state level, agricultural and economic development concerns are the primary drivers.

The actual cost of the incentives to the Federal and state governments is a complex issue and difficult to quantify. Because the most important Federal incentives are implemented as excise tax exemptions or structured to be equivalent to excise tax exemptions, the cost to the government is less than if they were implemented as tax credits. In addition, the fact that motor fuels taxes are assessed volumetrically, and ethanol has only about two-thirds of the energy content as gasoline means that the government receives more tax revenue per mile for ethanol than for gasoline.

Ethanol production creates both agricultural and manufacturing jobs, which increase government tax revenues that accrue from producer profits, payroll taxes, and income produced by secondary sources (i.e., from the economic multiplier effect). Ethanol production also has the benefit of displacing foreign energy sources, primarily petroleum and MTBE. Some states in which ethanol production plants are located have sponsored studies to quantify the net effect of ethanol production on both state and Federal tax receipts, and they have shown a net increase in tax revenues after the incentives are accounted for. State analyses consider the extra revenue received from higher corn prices due to the increased demand for corn for ethanol production. Remove parentheses. Most state-sponsored studies focus mainly on the issues mentioned in this paragraph and not the tax issues noted above. Those issues are considered separately by tax experts. After discounting the inflated benefits based on the studies' optimistic premises, the revenue raising aspects of ethanol production remain significant, especially at the state level. An important part of the state analyses is the extra revenue received from higher corn prices due to the increased demand for corn for ethanol production.

Federal Tax Incentives

The most important Federal incentives for ethanol are a partial exemption to the Federal motor fuels excise tax for gasohol, i.e., ethanol blends of 10 percent or less, and an income tax credit for ethanol used as a motor vehicle fuel. Both incentives are nominally worth up to 54 cents per gallon of ethanol. The motor fuels tax exemption is typically more advantageous for ethanol used in gasohol, since the income tax credit is limited by the taxpayer's tax liability and is more complex to administer. For neat

fuels, i.e., blends containing at least 85 percent ethanol, the excise tax exemption is between 5 and 6 cents, so the income tax credit is normally more advantageous. Most of the ethanol used today is blended into gasohol and only small amounts are used as neat fuels. The income tax credit also provides an additional 10 cents per gallon credit for small producers.

On June 9, 1998, President Clinton signed the Transportation Bill, which extended the ethanol tax incentives to 2007, but on a declining schedule. The incentives will remain equivalent to 54 cents per gallon of ethanol through 2000. In 2001, they decline to 53 cents per gallon; in 2003 they decline to 52 cents per gallon; and in 2005 they decline to 51 cents per gallon. The Federal ethanol tax incentives have proved to be politically resilient and may be further extended after 2007. The Midwest farm states have been very successful in lobbying Congress to extend the incentives. In addition, Iowa is an early presidential primary state, and aspiring candidates have so far been unwilling to anger Iowa voters over a farm issue. Congress can also point to the country's commitment to the development of renewable, environmentally friendly fuels.

The current corn-based ethanol industry is dependent on the ethanol tax incentive, and this incentive is essential to the emerging cellulosic-based ethanol industry. Until ethanol production prices decrease to the point where they are competitive with gasoline, the stability of the ethanol tax incentive is absolutely necessary to spur investments in ethanol production facilities.

The motor fuels taxes for gasoline and ethanol blends are listed in Table 1. The tax per gallon of gasoline is 18.4 cents. Three gasohol blends, E10, E7.7, and E5.7, containing ethanol derived from biomass are granted partial excise tax exemptions, which effectively lowers their tax rates. The partial exemption for E10 is 5.4 cents per gallon, for an effective tax rate 13.0 cents per gallon. This is equivalent to an exemption of 54 cents per gallon of ethanol. Originally, the gasohol exemption applied only to E10, but Congress extended the exemptions to E7.7 and E5.7. The tax rates for these two gasohol blends are derived proportionately, so that the equivalent exemption per gallon of ethanol is also 54 cents. Their tax rates are 14.24 and 15.32 cents per gallon, respectively. The tax on neat fuels, ethanol blends of 85 percent or greater, is slightly less than 13.0 cents per gallon because neat fuels enjoy an additional exemption of one-half of the leaking underground storage trust (LUST) fund, which was reintroduced as of October 1, 1997 at 0.1 cents per gallon. The current tax on neat fuels is 12.95 cents per gallon. However, the equivalent subsidy per gallon of ethanol for these blends is 5.4 and 6.41 for cents per gallon, for E100 and E85 respectively, far less generous than for gasohol.

Table 1. Federal Motor Fuels Excise Taxes for Gasoline and Ethanol Blends
(Cents per Gallon)

Type of Fuel	Federal Motor Fuels Tax Rate	Exemption Rate per Gallon of Fuel (Compared to Gasoline)	Exemption-Rate Equivalent per Gallon of Ethanol
Gasoline	18.4	not applicable	not applicable
Gasohol, E10	13.0	5.4	54
Gasohol, E7.7	14.24	4.16	54
Gasohol, E5.7	15.32	3.08	54
E85 and above	12.95	5.45	6.41 (E85) to 5.4 (E100)

The alcohol fuels income tax credit is the sum of (i) the alcohol mixture credit, (ii) the alcohol credit, and (iii) the small producer ethanol credit (Table 2). The alcohol fuels tax credit applies to alcohol mixed with gasoline and used as a fuel, while the alcohol credit applies to alcohol not mixed with gasoline or other special fuel other than a denaturant and used as a fuel. For ethanol, both of these credits are 54 cents per gallon. The small ethanol producer credit is 10 cents per gallon, but is limited to the 15 million gallons for producers that have an aggregate production capacity under 30 million gallons per year.

Table 2. Alcohols Fuels Income Tax Credit for Ethanol

Type of Alcohol Fuels Credit	Description	Maximum Credit Amount (Cents per Gallon)
Alcohol Mixture Credit	Alcohol blended with a qualifying motor fuel	54 cents for 190 proof and above 40 cents for 150 to 190 proof
Alcohol Credit	Alcohol not mixed with gas or special fuel other than a denaturant	54 cents for 190 proof and above 40 cents for 150 to 190 proof
Small Producer Credit	Production capacity must be less than 30 million gallons per year.	10 cents for up to 15 million gallons

Notes: (1) The alcohol fuels income tax credit is subject to the general business tax credit limitations, must be reduced by any motor fuels excise tax exemption, and must be reported as gross revenue.
(2) The small producer credit applies primarily to niche markets and is of minimal importance. It is subject to aggregation rules.

The alcohol fuels credit can only be taken against the blender's[5] Federal tax liability at the end of the tax year and is subject to the general business tax restrictions, i.e., it applies only to a tax liability greater than certain other tax credit and the larger of 25 percent of the taxpayer's regular tax liability or $25,000 and the alternative minimum tax liability. The credit must be reduced by any motor fuel excise tax exemption taken. In addition, the allowable credit must be reported as gross income for the tax year in which the credit is earned even if the credit that can be taken that year is less than the allowable credit[6]. If the blender taking the credit does not have a sufficient Federal tax liability, he cannot claim the full credit allowable for the tax year. The Internal Revenue Code provides a carryback and carryforward period for unused tax credits. However, the carryforward period for unused alcohol fuel credits is more limited than the standard carryforward period for general business tax credits[7].

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[5]Usually the blender takes the alcohol mixture and alcohol credits, as the credits apply primarily to the person mixing the ethanol or dispensing it at the retail level. The producer will take any small producer credit.

[6]Only two income tax credits must be reported as gross income: the alcohols fuels credit and the gasoline tax and special fuels credit. This later credit applies to tax credits taken for excise taxes paid for fuels used for farming, non-highway use, school buses, and other nontaxable purposes. Only the alcohol fuels credit has the additional requirement that the total credit allowable must be included as gross income, even if the taxpayer can not claim the full allowable credit. The unclaimed credit is subject to the carryback and carryforward rules.

[7]The carryforward period currently expires at the end of 2003. However, an earlier termination may occur if the Highway Trust fund financing rate under Code Sec. 4081 ceases to exist. In that case, the credit may not be carried forward to tax years beginning after the two tax years following the tax year in which the rate ceased to exist.

When either the excise tax exemption or the income tax credit can be taken, the excise tax exemption is generally preferred by taxpayers[8]. The taxpayer always gets the benefit of the full excise tax exemption, whereas the taxpayer may have an insufficient tax liability to claim the entire tax credit allowable. Moreover, the full allowable tax credit must be reported as gross income and is taxed at the taxpayer's marginal rate, even if the taxpayer cannot take advantage of the full credit, which could reduce nominal value of the tax credit. The tax credit also imposes additional bookkeeping and tracking requirements, since the credit must be reduced by any excise tax exemptions, even if they are claimed by another taxpayer. To the taxpayer, the gasoline excise tax credit is immediate, whereas the income tax credit is taken at the end of the year (or when filing quarterly estimated tax payments) after the income tax liability is computed.

State Incentives

Approximately 20 states currently offer some sort of ethanol incentive, which may take the form of a blender credit, producer credit, income tax deduction, motor fuel excise tax exemption, or sales tax reduction. Whether the current state incentives will continue or whether additional states will provide incentives is speculative, especially if a large cellulosic ethanol industry emerges. Five states provide an exemption from the motor fuels tax for gasohol (Table 3). In four states, the exemption is a penny or two per gallon of gasohol, equivalent to 10 to 21 cents per gallon of ethanol, assuming a 10 percent ethanol blend. The excise tax exemption in Alaska is 8 cents per gallon for gasohol for ethanol produced from wood, equivalent to 80 cents per gallon for ethanol. This is by far the largest incentive provided by any state. The Alaska excise tax exemption had originally applied to all biomass ethanol, but legislation recently enacted to restrict the exemption to alcohol produced from wood.

The outright blender/producer credits vary considerably from state to state, and range up to 40 cents per gallon of ethanol (Table 4). Some states, however, impose limits on the amount of funds available for ethanol incentives. State incentives, while not as generous as Federal incentives, can play a pivotal role in the decision to build an ethanol facility.

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[8]The Treasury's position is that the tax credit provides the same benefit as the excise tax exemption, provided there is a sufficient tax liability. Treasury does note that some cost of money differences could arise depending on when the income tax credit is taken. This is especially true if some of the credit is carried over to future years. However as noted in the text, the income tax credit requires additional bookkeeping and tracking of the fuel to see if other taxpayers claim any excise tax credits. Currently, almost all ethanol is used in gasohol and almost all the ethanol incentives are claimed as excise tax credits.

Table 3. State Motor-Fuel Tax Exemption for Gasohol
As of November 1996

State	Exemption for Gasohol (Cents per Gallon of)	Equivalent Exemption for Ethanol (Cents per Gallon)
Alaska	8.0 Applies only to ethanol produced from wood	80 Applies only to ethanol produced from wood
Connecticut	1.0	10
Idaho	2.5	25
Iowa	1.0	10
South Dakota	2.0	20

Source: U.S. Department of Transportation, Federal Highway Administration, "Monthly Motor Fuel reported by States", February 1998 and legislation enacted in Alaska first quarter 1998

State incentives are typically motivated by agricultural support and economic development objectives. Creating additional demand for agricultural products benefits farmers, who receive higher prices for their produce, and states, whose tax revenues are increased as farmers enjoy greater profits. The ethanol conversion plants create in-state jobs, thus increasing payroll taxes, and taxable profits. These incentives also benefit state trade balances by reducing the amount of gasoline that must be purchased from other states or foreign countries. State tax incentives are normally justified by studies that show a net tax benefit accruing from the incentives.

**Table 4. State Ethanol Incentives Other than Motor Fuel Tax Exemptions for Gasohol
As of April 1997**

State	Incentive
California	One-half of the gasoline fuel excise tax credit for E85. Neat fuels are exempt from fuel taxes. Current excise taxes for gasoline and E85 are 18 and 9 cents per gallon, respectively
Hawaii	Exempt from retail sale tax (4 percent)
Illinois	2 percent sales tax exemption
Louisiana	Gasohol is exempt from sales tax if alcohol is made in the state
Indiana	10 percent income tax deduction for plants that upgrade
Minnesota	15 cents per gallon of ethanol, capped at $3.75 million per year for each producer
Missouri	20 cents per gallon of ethanol produced in state
Montana	30 cents per gallon of ethanol produced in state with state agricultural products, $6 million cap on a first-come basis
Nebraska	25 cents per gallon of ethanol, capped at $25 million per year for each producer
North Carolina	Income tax credit up to 30 percent plant cost
North Dakota	40 cents per gallon of ethanol produced and sold within North Dakota, $3,675,000 authorized in 1995
Ohio	1 cent per gallon of E10 income tax credit, equivalent to 10 cents per gallon of ethanol, maximum of $15 million per year
Oregon	50 percent property tax credit for ethanol facilities
South Dakota	20 cents per gallon of ethanol produced in state, $208,667 funding cap
Washington	Credit of 60 percent of tax rate for each gallon of alcohol blended
Wyoming	40 cents per gallon of ethanol, through 2000

Source: *Clean Cities Guide to Alternative Fuel Vehicle Incentives*, U.S. Department of Energy, November 1996 and *The Clean Fuels Report*, April 1997 and U.S. Department of Transportation to promote the development of alternative fuels, Federal Highway Administration, "Monthly Motor Fuel reported by States", February 1998

Cost of Tax Incentives to the Government

The cost of the tax incentives to the government can be divided into two categories: (1) the impact on tax revenues from a fiscal tax policy point of view which assumes GDP remains fixed and (2) the taxes on additional taxable income generated from producing ethanol, i.e., from an increase in GDP.

The first category is applies to tax incentives like the Federal excise tax exemption and the income tax credits. The nominal value of these incentive overstates the change in total government tax receipts or the actual cost of the incentive to the government for two reasons. First, IRS regulations effectively treat the ethanol incentive as gross revenue, which is taxed at the taxpayer's marginal tax. Second, liquid motor fuel taxes are assessed volumetrically, but ethanol has only about two-thirds the energy content of gasoline for an equal volume. For the same miles driven, approximately 50 percent more ethanol is used by volume and, consequently, the tax receipts are 50 percent greater. A recent analysis of the ethanol tax incentives estimated that the actual cost to the Federal government of the 54 cent per gallon ethanol tax incentives is 34 cents per gallon[9]. This is the actual tax revenue forgone by the federal government because of the excise tax incentives, assuming that GDP remains constant. The study also estimated that the actual decrease to federal and state tax revenues due to the combined federal and state tax incentives was about 50 percent of the incentive level.

The second category deals how the ethanol incentives increase GDP. Several factors are involved here. The ethanol industry creates additional jobs not only in the ethanol industry itself but also from the economic multiplier effect. Ethanol also displaces some foreign source oil and/or MTBE, which will add to domestic taxable receipts and improve the nation's trade balance. Indirectly, ethanol may lower the price of oil or MTBE through decreased demand for these products. Ethanol will increase the demand for agricultural products and consequently increase the prices farmers receive.

As noted above, no objective economic studies exist at the current time for quantifying the effects of ethanol production on GDP. While it seems obvious that ethanol production will increase GDP, especially since it replaces some imported products, quantifying the extent of the increase is difficult. The question is to what extent the ethanol industry will create new jobs, capital, and so forth as opposed to displacing jobs, capital investment, and so forth from other sectors.

The farming issue is more intricate. Since ethanol increases the demand for agricultural products, farmers will receive higher prices. For farm states, this will produce additional taxable income for two reasons. The farmers will sell more agricultural products and they will receive higher prices for all the products sold (prices increase because of the greater demand for the product). Any in-state ethanol production facilities also increase state taxable revenues and provide economic development. These

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[9]David Andress, Ethanol Tax Incentives and Issues, David Andress & Associates, Inc., April 1998

additional tax revenues may more than offset any state tax incentives and clearly justify state tax incentives.

From a national perspective, however, consumers in other states pay more for farm products, and this reduces their taxable income. That is, the higher prices received by the farmers are to some extent offset by the higher prices domestic consumers pay for farm products. However, some of the produce may be exported, and the higher prices received by the farmers are a net national benefit.

The farm story is more complicated than the simple discussion above indicates. Until the passage of the recent 1996 Freedom to Farm bill, the Federal government took a much more active role in managing farm-product inventories. The government would pay a farmer not to plant designated land, would buy excess farm inventory under certain conditions, and would guarantee certain farm produce prices. A goal of the new farm bill is to transition planting decisions to a market-based, rather than government-controlled, environment, and to eliminate farm support payments. Whether the government will have to step in to remedy conditions caused by market inefficiencies is unknown, but there are indications that this may be necessary in some cases. Before the 1996 farm bill was passed, the ethanol incentives indirectly played a role in the government's overall farm support policies. Department of Agriculture analyses showed how government corn support payments would increase if the ethanol incentives were repealed. Although those analyses are no longer relevant, they still provide some useful insights into the relationship between the ethanol incentives and corn prices and what costs might accrue to a government assistance program if corn prices were to precipitously drop.

Analyzing the economic impact of the corn ethanol industry on corn crops is exceedingly difficult, since corn is a feed commodity and the corn mills produce other products besides ethanol, some of which are exported. The economic relationship between ethanol mill co-products and corn and soy products must also be considered, as these products are animal feed substitutes for each other. The situation is less complicated for cellulosic ethanol. Most of the feedstock crops do not have an alternative food use and the co-product associated with cellulosic ethanol conversion is electricity.

The prospect of global warming has stimulated an international effort to develop policies to reduce anthropogenic carbon emissions. One strategy being considered in the U.S. is the use of carbon taxes or incentives. Cellulosic ethanol produces almost no net carbon emissions and would be favored by any policies that internalize the cost of greenhouse gas emissions. Chapter 7 discusses this issue in detail.

Energy Policy Act of 1992

In EPACT, Congress put forth a comprehensive strategy for meeting the nation's future energy demands. One of the key features of the act is to reduce the nation's dependency on oil and encourage the development of alternative fuels. The act defines a set of alternative fuels, which include ethanol

(E85), methanol (M85), other alcohols in mixtures of 85 percent or more by volume (but not less than 70 percent by rule) with gasoline, compressed natural gas, liquified natural gas, liquified petroleum gas, hydrogen, electricity, biofuels, or any fuel substantially not petroleum and yielding substantial security and environmental benefits. EPACT requires certain fleets to use these fuels according to a schedule specified in the act, and establishes a set of tax incentives for alternative fueled vehicles (AFV) and AFV refueling facilities. EPACT also establishes objectives for reducing petroleum usage.

Requirements For Alternative Fueled Vehicles (AFV)

The EPACT fleet requirements for alternative-fueled vehicles can be met by any alternative fuel listed above. As ethanol is just one of the alternative fuels, it must compete with other alternative fuels. Fleets covered under EPACT are divided into four categories: Federal, state, alternative fuel provider, and municipal/private. EPACT specifies a schedule of AFV requirements for each category (Table 5). Minimum fleet sizes for EPACT coverage are 20 light duty vehicles for state fleets and 50 for private fleets with availability to alternative fuels. Certain exemptions apply. The number of AFVs currently covered under EPACT is very small. The energy Information Administration (EIA) estimates that alternative fuels from EPACT-mandated fleet requirements will account for at most 3 percent of the highway transportation fuels by 2010.

Table 5. EPACT AFV Fleet Purchase Requirements
(Percent of New Acquisitions)

Year	Federal	State	Alternative Fuel Provider	Municipal/Private (a)
1998	50	15	50	20
1999	75	25	70	20
2000	75	50	90	20
2001	75	75	90	20
2002	75	75	90	40
2003	75	75	90	60
2004	75	75	90	70
2005	75	75	90	70
2006	75	75	90	

(a) May be required by regulation if DOE finds these acquisitions are necessary.

EPACT Tax Deductions

EPACT provides tax deductions from adjusted gross income for qualified AFVs based on vehicle weight (Table 6). The tax deduction is as available for both business and personal vehicles. EPACT also provides tax deductions of up $100,000 for AFV refueling facilities.

Table 6. EPACT Tax Deductions for AFVs

Truck or Van		Bus	All Other Vehicles
10,000 to 26,000 Lb.	> 26,000 lb.	Seating for 20+ adults	Not including off road vehicles
$5,000	$50,000	$50,000	$2,000

The tax deductions are reduced by 25 percent in 2002, 50 percent in 2003, and 75 percent in 2004. They expire on December 31, 2004.

EPACT authorizes Federal grants for state-administered incentive programs to promote and encourage the use of alternative fuels. Under this program, the states design their own programs and submit them to the Federal government for approval. It is expected that the ethanol producing states will design theirs to increase ethanol usage. The state incentives can be structured to provide grants for the introduction of AFVs into state-owned fleets, which do not benefit from the income tax deductions.

Petroleum Reduction Targets

EPACT establishes a goal of displacing 10 percent of nation's petroleum use with replacement fuels by 2000 and 30 percent by 2010. The petroleum reduction targets provide statutory and policy justification for establishing government programs to encourage the development of alternative fuels. The objective of these programs is to provide basic research and development (R&D) to commercialize a domestic industry for clean fuels. The government has a long and successful history of encouraging the development and use of new energy sources. The oil depletion allowance provided a tremendous incentive to the petroleum industry, and the nuclear power industry benefitted from many government R&D programs.

Alternative Motor Fuels Act of 1988

The purpose of Alternative Motor Fuels Act of 1988 (AMFA) is to encourage the development and use of alternative fuels, including ethanol, methanol, and natural gas. AMFA laid the groundwork for much of the treatment of alternative fuels in EPACT. AMFA also provides an incentive to car manufacturers for producing AFVs. A gallon of alternative fuel used in an alternative fuel vehicle is counted in the calculation of the manufacturer's Corporate Average Fuel Economy (CAFE) as

equivalent to 15 percent of a gallon of gasoline. AMFA bases the CAFE credit on the assumption that dedicated fueled vehicles use alternative fuels 100 percent of the time and flexible fueled vehicles use gasoline 50 percent of the time and alternative fuels the other 50 percent of the time. These credits accrue to each dedicated and flexible fueled vehicle until they reached 0.5 and 1.0 percent of new vehicle sales, respectively, in each model year. The maximum increase in CAFE attributable to flexible fueled vehicles is 1.2 mpg. There is no limit on the increase in the CAFE mpg displaced on dedicated fueled vehicles. The CAFE credits scheduled to expire in 2004. Because of these incentives, automobile manufacturers are currently selling flex-fueled vehicles, e.g., the Ford Taurus and the Chevy Lumina.

The Clean Air Act Amendments of 1990

The CAAA requires certain fleets, generally defined as consisting of 10 or more vehicles capable of being centrally fueled, operating in non-attainment metropolitan areas with 250,000 or more people to use clean fuels. Non-attainment areas are those areas that violate ozone or carbon monoxide standards set by EPA. EPA specifies emission standards for fuels to meet in order to be classified as clean fuels. Clean fuels include all the alternative fuels plus any conventional and reformulated gasoline, and diesel and clean diesel fuels that meet the EPA emission criteria.

Reduction of Agricultural Wastes and Forest Residues

Management of agricultural wastes and forest excess residues is an increasing problem in many areas of the country. At the present time, some agricultural wastes are burned and forest residues increase the risk of wildfires, both of which contribute to air pollution problems. Biomass ethanol production may provide an attractive alternative for handing these wastes, and some environmentally friendly states also grant special tax incentives to ethanol plants using waste products. In some cases, the ethanol producer may receive a tipping fee for handling the waste, such as has occurred with municipal solid wastes.

3. Emission and Fuel-Characteristic Issues

The Clean Air Act Amendment of 1990 and EPA Regulation

The CAAA is a watershed piece of legislation designed to improve the nation's air quality. The act assigns the responsibility for regulating the emissions of the so-called criteria pollutants to the Environmental Protection Agency (EPA). Table 7 summarizes recent gasoline parameters parameter values. The key parameters affecting ethanol are the maximum percent of alcohol and ethers allowed, oxygen-concentration requirements and restrictions, and the maximum allowable RVP.

Low-level blends of ethanol and gasoline are currently limited to a maximum of 10 percent ethanol, which corresponds roughly to a 3.5 weight percent of oxygen. For other alcohol and ether blends, except methanol blends, the maximum oxygen concentration of the blend is limited 2.7 weight percent by EPA under the "substantially similar" to gasoline requirement of the Clean Air Act Section 211(f)(1). Methanol blends containing no other oxygenates are limited to 0.3 percent methanol by volume. Table 8 shows the volume percentages for alcohol and ether blends for key oxygen concentrations. The maximum ethanol excise tax incentives occur at the ethanol volumetric percentages associated with these oxygen concentrations.

Reid Vapor Pressure

RVP is regulated to control evaporative VOC emissions that contribute to ozone formation. Ozone results from photochemical reactions with certain organic and nitrogen compounds contained in fuel evaporative and tailpipe emissions. Because the rate at which the reactions proceed is related to both temperature and intensity of the sunlight, ozone problems are greater in the summer than in the winter. Ethanol blended with conventional gasoline at a concentration of 10 percent by volume, is granted a one-psi RVP waiver (CAAA, Section 211), which corresponds roughly to an RVP increase of a 10-percent ethanol blend (Table 9). No RVP or VOC waiver is granted for other ethanol-gasoline blend levels or for ethanol blended with RFG. The RVP waiver is primarily a concern for summer gasoline production, because summer gasoline has stricter RVP limits than winter gasoline. The lack of an VOC waiver for RFG inhibits the blending of ethanol with summer RFG, because a lower RVP RFG must be produced to allow for the RVP increase caused by ethanol. Ethers like ETBE and MTBE have the advantage of not producing an increased RVP mixture when blended with gasoline. Neat ethanol has a very low RVP.

Table 7. Fuel Parameter Values (national basis)

	Conventional gasoline		Gasohol	Oxyfuel (2.7 wt% oxygen)	Phase I RFG
	Avg[1]	Range[2]	Avg	Avg	Avg
	-------	--------	------	------	---------
RVP[3] (psi)	8.7-S 11.5-W	6.9-15.1	9.7-S 11.5-W	8.7-S 11.5-W	7.2/8.1-S 11.5-W
T50 (ϕF)	207	141-251	202	205	202
T90 (ϕF)	332	286-369	316	318	316
Aromatics (vol%)	28.6	6.1-52.2	23.9	25.8	23.4
Olefins (vol%)	10.8	0.4-29.9	8.7	8.5	8.2
Benzene (vol%)	1.60	0.1-5.18	1.60	1.60	1.0 (1.3 max)
Sulfur (ppm)	338	10-1170	305	313	302 (500 max)
MTBE[4] (vol%)	--	0.1-13.8	--	15	11 (7.8-15)
EtOH[4] (vol%)	--	0.1-10.4	10	7.7	5.7 (4.3-10)

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1 As defined in the Clean Air Act.
2 1990 MVMA survey.
3 Winter (W) higher than Summer (S) to maintain vehicle performance.
4 Oxygen concentrations shown are for separate batches of
  fuel; combinations of both MTBE and ethanol in the same
  blend can never be above 15 volume percent total.
Source: EPA web site

Table 8. Alcohol and Ether Blend Volume Percentages for Key Oxygen Concentrations

Oxygen Concentration (weight percent)	Ethanol Volume Percent	ETBE Volume Percent	MTBE Volume Percent
2.0	5.7	12.7	11.1
2.7	7.7	17.2	15.0
3.5	10.0	N/A	N/A

Table 9. RVP Values for Ethanol and Ether Blends

Percent of alcohol / ether	RVP for Ethanol Blend (psi)	RVP for ETBE Blend (psi)
0	9.00	9.00
5	10.10	8.80
10	10.00	8.60
15	9.90	8.30
20	9.75	8.10
25	n/a	7.90
30	9.50	n/a
50	8.70	n/a
70	7.00	n/a
90	4.30	n/a
100	2.30	4.40

Oxygenated Fuel

The CAAA requires the use of oxygenated fuels in winter carbon monoxide non-attainment areas. The act requires a minimum oxygen concentration of 2.7 weight percent, the highest allowed for ether blends. Ten-percent ethanol blends can be used to obtain an oxygen concentration of about 3.5 weight percent.

In a so-called perfect combustion only carbon dioxide is produced; carbon monoxide is the result of incomplete combustion occurs when carbon in the fuel is partially, rather than fully, oxidized.

Incomplete fuel combustion is more pronounced when operating below design temperatures, and consequently, carbon monoxide emissions increase in wintertime when they are even further exasperated by longer warm-up periods. Carbon monoxide can cause health problems because it reduces the flow of oxygen in the bloodstream and is particularly dangerous to people with vascular problems.

Ozone Reduction

Urban ozone problems increase dramatically in the summer, and the CAAA requires the use of RFG during the summer in extreme or serious ozone non-attainment areas. The CAAA also provides an option to use RFG in areas with moderate or marginal ozone non-attainment problems. EPA requires a minimum 2.0 weight-percent oxygen concentration for RFG. EPA had imposed a 2.7 maximum weight-percent oxygen concentration, which corresponds to an MTBE blend of 15 percent by volume. However, in the December 1993 final rule (59 FR 7716, February 16, 1994), EPA issued a rule that maintained the 2.7 weight-percent cap, but allowed a state to request a higher cap of 3.5 weight percent if it had no ozone exceedances for the previous three years. This exception was introduced to allow RFG containing 10 percent ethanol blends, as ethanol is presently the only oxygenate which legally can be blended at levels greater than 2.7 weight-percent oxygen (on average). As noted above, no RVP waiver applies to RFG containing ethanol.

NOx is an ozone precursor, and questions have been raised about whether the addition of fuel oxygenates will lead to an increase in NOx emissions. The issues here are complex, and differences of opinions exist about whether NOx emissions increase and/or whether air quality will be effected. If NOx emissions do increase, ethanol blends typically show a greater increase than ether blends. EPA maintains that for VOC-controlled RFG, its Complex Model shows no increase in NOx emissions when the oxygen concentration is increased from 2.0 to 2.7 weight percent (40 CFR Part 80). EPA also maintains that increasing the oxygen level to 3.5 weight percent will not increase NOx emissions. (NOx emissions will increase when non VOC controlled gasoline is used.) EPA notes that others may disagree with this conclusion and that some experimental data show that NOx emissions increase. EPA recognizes that some states may conclude that lower maximum oxygen limits are needed to maintain air quality and allows a state to request lower maximum oxygen levels for VOC controlled gasoline. Such a request has been approved for California.

The upcoming RFG Phase II specifications, beginning in 2000, may make it economically unattractive to use ethanol as an RFG blend feedstock for the summer season. Phase II RFG requires a 27 percent reduction in VOC as opposed to the 17 percent reduction required by Phase I RFG.   Ethanol's one-psi boost to RVP presents refiners with a difficult problem. OXY-FUEL News estimated an RVP of 8.1 psi would meet the Phase I requirements, which would mean a subgrade gasoline suitable for

blending with ethanol would have to have an RVP of 7.1 psi. For Phase II requirements subgrade gasoline suitable for blending with ethanol would have to have an RVP of 5.5 psi[10].

The reason for controlling RVP is based on assumptions about the relationship between RVP and ozone. Evaporative VOC emissions are related to RVP; VOCs are ozone precursors. However, the spectrum of evaporative VOCs emitted depends on the type of fuel, and different VOCs have different ozone-forming or reactivity potentials. EPA is currently funding the National Academy of Sciences (NAS) to study this issue and to characterize the extent to which ethanol blends contribute to additional ozone formation. A report is scheduled for completion in February 1999. If the NAS study determines ethanol blends do not increase ozone, EPA may revise its RVP standards for ethanol blends. However, the California Air Resources Board recently completed a study on the ozone forming potential associated with an RVP waiver for California RFG and concluded that an RVP waiver for ethanol blends would lead to an increase of 16 to 19 percent in ozone forming potential because of higher evaporative emissions[11].

The National Renewable Energy Laboratory (NREL) did a study comparing the characteristics of ethanol blends and neat ethanol compared to year 2000 RFG (Table 10). For ethanol splash blended with RFG (E10), which would not satisfy the phase II RVP requirements, the evaporative VOCs increase by 30 percent compared with RFG. However, if low RVP subgrade RFG is produced so that the ethanol blend meets the Phase II RFG requirements, evaporative VOCs do not increase. In contrast to the EPA's position, the NREL results project an increase in NOx emissions for ethanol blended with both normal RFG and low RVP RFG. EPA maintains that its Complex Model does not show a NOx increase for VOC controlled gasolines. Table 10 also highlights the ozone benefits of neat ethanol. Both E85 and E95 show significant reductions in evaporative VOC and NOX emissions.

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[10]EPA Should Reconsider Ethanol For Phase II Gasoline, Says Refiner, OXY-FUELS News, March 16, 1998, p.1

[11]Proposed Determination Pursuant to Health and Safety Code Section 43830(g) of the Ozone Forming Potential of Elevated RVP Gasoline Containing 10 Percent Ethanol, October 1998, Air Resources Board, Sacramento, California

Table 10. Comparison of RVP, VOC, CO, and NOx for year 2000 RFG

	RFG (11 percent MTBE)	E10 (splash blended)	E10 (low RVP)	E85	E95
	g/mile (except as noted)	% change	% change	% change	% change
RVP (psi)	6.7	8.1	6.7		
Evaporative VOC	0.204	30	0	-15	-28
Exhaust VOC	0.208	-2	-2	-2	-2
Total VOC	0.412	15	-1	-8	-15
CO	2.19	-4.6	-4.6	-4.6	-4.6
NOx	0.635	2.9	2.9	-20	-20

Source: Tyson, Shaine, "Fuel Cycle Evaluation of biomass-Ethanol and Reformulated Gasoline"
NREL/TP-463-4950, Table E-13

State Oxygen Regulations

California, because of its unique air quality problems, has adopted stricter criteria for RFG sold in California than is required by the Federal RFG program. EPA has approved the California RFG requirements and has determined it will provide as good or better air-quality benefits as federal RFG. Table 11 summarizes some of the characteristics of Federal and California RFG relative to conventional gasoline. The values shown in the table are average values. Table 12 shows the so-called flat, average, and cap specifications.   The RVP requirements apply to non-winter months for certain specified locations. Oxygen limits are explained below.

A refiner may choose either the "flat" limit or the "averaging" limit for all the Phase 2 standards except for Reid vapor pressure and oxygen concentration. The flat limit applies to every batch of finished gasoline. The "averaging" limit allows specific batches to exceed the "flat" limit as long as fuel produced over a 180-day period meets the "averaging" limit and never exceeds the "cap" limit. The "averaging" specifications give refiners more blending options and help them control operating costs.

As an alternative to the flat or averaging limits, California allows refiners to develop their own gasoline specifications as long as the refiners can show that emission effects are equivalent to those of the limits using a Predictive Model developed by the California Air Resources Board or use an emissions test program to demonstrate the equivalency.   The cap limits still apply. Oxygen concentrations of up to 2.7 weight percent are allowed under this option. Under this program, minimum oxygen concentration is required for summertime California RFG.

Concern about increased NOx emissions from the use of oxygenated fuels was a major reason why California settled on lower maximum oxygen concentrations. These restrictions virtually eliminate the use of ethanol in blends; California law permits a one psi RVP allowance for E10 (3.5 percent oxygen in conventional gasoline), but not for lesser blend levels. In addition California's Predictive Model, which refiners can use to demonstrate a fuel blend meets California air quality standards, limits fuel vapor pressure to 7.0 psi. For the most part, refiners have been unwilling to produce subgrade gasolines that can be blended with ethanol at a 2 percent oxygen limit, without the RVP waiver[12]. Consequently, most of California oxygenate requirements are being met by MTBE. California is in the process of studying options that would allow fuels to contain oxygen levels greater than 2.7 percent, provided they meet California emissions requirements.

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[12]Tosco has announced a small pilot program to produce MTBE-free fuel by blending ethanol to meet California oxygenate standards

Table 11. Federal and California Reformulated Gasolines Compared to California 1994 Conventional Gasoline

	Federal RFG		California RFG
Implementation Dates	Phase I 1/1/95 (retail)	Phase II 1/1/2000 (retail)	3/1/96 (producer)[1] 6/1/96 (retail)
Areas Affected	L.A. County Orange Riverside Sacramento (6/96) San Bern. (part) Ventura San Diego	Same as 1995	Statewide
Emissions Reductions (%) (Date) Volatile Organic Compounds Nitrogen Oxides Carbon Monoxide Sulfur Dioxide	(1996) 9 4 11 0	(2000) 15 4 11 0	(1996) 17 11 11 80
Reduced Cancer Risk (%)[2]	20-30	30-40	30-40
Fuel Properties[3] Reid Vapor Pressure (RVP), psi Oxygen, wt.% Benzene, v.% Aromatics, v.% Olefins, v.% Sulfur, ppm Distillation temperatures T50, ºF T90, ºF	7.0 2 0.8 27 8.5 130 210 329	6.7 2 0.8 25 8.5 130 207 321	6.8 2 0.8 22 4 30 200 290
Production Cost Increase (cents/gallon)	2-5	unknown	5-15[4]

1. California RFG will satisfy federal Phase 2 RFG requirements.
2. Analysis includes an adjustment for methyl tertiary butyl ether (MTBE).
3. Specifications for gasolines that could comply with Federal and California RFG regulations.
4. Average of 10 cents per gallon -- based on individual refiner production costs.
Source: CARB web site

Table 12. California Cleaner-Burning Gasoline Specifications

Specifications	Phase 1 *	Phase 2 "Flat"	Phase 2 "Averaging"	Phase 2 "Cap"
Reid vapor pressure (psi)	7.8	7.0	7.0	7.0
Sulfur (ppmw)	151	40	30	80
Aromatic HC (vol.%, max.)	32	25	22	30
Benzene (vol.%, max.)	1.7	1.0	0.80	1.20
Olefins (vol.%, max.)	9.6	6.0	4.0	10.0
Oxygen (wt.%)**	1.8-2.2	1.8-2.2	NA	1.8 min 2.7 max
Temperature (oF, max.) at 50% distilled	212	210	200	220
Temperature (oF, max.) at 90% distilled	329	300	290	330

*   Specifications are only for Reid vapor pressure. The other numbers are estimates of average
     values for Phase 1.
** The oxygen specification (1.8-2.2 percent) has been in force during winter months
only since November 1992. The Phase 2 specification is year-round.
Source: CARB web site

Minnesota Oxygen Requirements

Minnesota has enacted legislation a minimum 2.7 percent oxygen content year round. Legislation has been introduced in Nebraska to require minimum oxygen content. The move toward requiring minimum oxygen standards for other than environmental reasons appears confined to the ethanol producing regions.

MTBE Toxicity Issues

Ground water contamination from Methyl Tertiary-Butyl Ether (MTBE) leaching from leaking underground fuel tanks is area of current concern. The problem is of great concern in California and the state has commissioned a study to look into the matter. At this time, some contamination in drinking water has been reported. While the number of confirmed incidents is small at the current time, they are taken quite seriously by state authorities because MTBE is considered a possible human carcinogen by the U.S. Environmental Protection Agency (EPA). MTBE has a disagreeable taste and odor at extremely low concentrations.

Data on spread rates and migration paths of MTBE are very preliminary as the use of widespread MTBE in gasoline has a limited history. Researchers have compared MTBE dispersion with plumes from benzene, toluene, ethylbenzene, and xylenes (BTEX). However, they have found evidence that MTBE is generally recalcitrant and not likely to undergo the rapid attenuation seen for the more biodegradable BTEX compounds.

California has recently completed a study examining the economics of alternatives to using MTBE in gasoline[13]. The options considered in the study were ethanol, ETBE, TBA (tertiary butyl alcohol), and TAME (tertiary amyl methyl ether). At this point in time, California has not determined that MTBE contamination is serious enough to warrant usage restrictions. One obstacle to banning MTBE is the lack sufficient quantities of substitute oxygenates. The study also looked at the possibility of eliminating the oxygen requirement or adopting a reduced oxygen requirement that would still allow the use of MTBE (H.R. 630). The study concluded that the disruption would be too great in the short term, but that a transition could be feasible in the long term (greater than six years). The cost changes for the MTBE alternatives are listed in Table 13.

Table 13. Average Cost Change for California MTBE Alternatives (Cents Per Gallon)		
	Intermediate Term	**Long Term**
Ethanol	6.1 to 6.7	1.9 to 2.5
ETBE	2.4 to 2.5	0
TBA	0.5 to 1.4	0.3 to 1.0
Mixed Oxygenates	-0.2 to 0.2	-0.3 to -0.4
HR 630	-0.2 to -0.8	-0.3 to -1.5
No Oxygenates	4.3 to 8.8	0.9 to 3.7

Source: Supply and Cost of Alternatives to MTBE in Gasoline, California Energy Commission, Staff Report, October 1998, Publication No: P300-98-013

The study noted that similar to MTBE, compounds such as ethanol, ETBE, TAME and TBA are able to mix with water, are difficult to remove from contaminated water and cause water to taste and smell unpleasant even at very small concentrations. This issue is being separately considered. Industry experts have suggested that the MTBE problem could apply to all ethers. Ground water contamination from leaky ethanol storage tanks does not appear to be a problem to date.

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[13]Supply and Cost of Alternatives to MTBE in Gasoline, California Energy Commission, Staff Report, October 1998, Publication No: P300-98-013

Other Emissions

Ethanol fuels show reductions in benzene, 1,3-butadiene, and exhaust hydrocarbons emissions, but show an increase in formaldehyde and acetaldehyde emissions. These emissions are regulated because of their carcinogenic potential. Ethanol fuels also reduce sulfur emissions. EPA is currently considering imposing further limiting of sulphur emissions. The changes in these emissions are proportional to the ethanol content of the fuel.

Advances in Engine and Emissions Technology

When fuel oxygenates were first proposed to improve air quality, most vehicles were using carbureted systems. Adding oxygenates was the major way to control the fuel/air mixture at that time. The oxygenates enleaned the fuel/air mixture, thereby increasing carbon dioxide emissions and reducing carbon monoxide emissions. Newer cars with electronic controls can monitor both the air/fuel mixture and the concentration of key gaseous emissions to dynamically control the amount of air, and hence oxygen concentration, in the fuel intake. While the benefits of oxygenated fuels are not as great for newer vehicles as they were for older, the benefits are still important. EPA stresses not only the carbon monoxide reduction, but the dilutive effect of oxygenates on sulfur, benzene, butadiene, and exhaust hydrocarbons emissions. Furthermore, any analysis of emissions reductions is skewed by the small proportion of high-polluting vehicles, where the benefit from oxygenated fuels is greatest.

4. Low-Level Ethanol Blends

This chapter describes the approach used to quantify the value of ethanol used in low-level blends and estimate an ethanol demand curve. Much of the material presented here is taken from the *Ethanol Demand in United States Gasoline Production*[14] report and the reader is referred to this document for more detail. The main tool used for the analysis is the Oak Ridge National Laboratory Refinery Yield Model (ORNL-RYM). ORNL-RYM , a detailed linear-programming representation of regional petroleum refining, determines the minimum refinery cost for a given set of premises and constraints, such as EPA vehicular emission requirements. Model runs are used to derive an ethanol demand curve by systematically varying ethanol prices, while keeping other assumptions and constraints fixed. ORNL-RYM is used to examine several sensitivity cases including higher oil prices, varying prices for MTBE, low sulfur gasoline requirements, higher RFG penetration, and higher allowable ethanol percentages.

Value of Ethanol in Low-Level Blends

Ethanol has a higher octane rating than gasoline and its use can displace highly toxic and potentially carcinogenic octane enhancers such as benzene, toluene, and xylene. As an oxygenate, ethanol can be used to meet EPA oxygen requirements for reducing carbon monoxide emissions. Ethanol competes primarily with MTBE in this arena. The use of ethanol also helps reduce some of the criteria pollutants regulated by EPA. In optimized blending, ethanol can further displace costly components of gasoline. On the down side, low-level ethanol blends have an increased Reid vapor pressure (RVP), which is associated with increased evaporative emissions, and may cause a slight rise in nitrous oxide emissions.

Volumetrically, ethanol has only about two-thirds of the BTU content as gasoline, which means approximately 1.5 gallons of ethanol have to be used to travel an equivalent distance as one gallon of gasoline. Consequently refiners must produce a greater volume of ethanol blends to meet a gasoline-equivalent energy demand. This requirement is most pronounced when ethanol is substituted for conventional gasoline as a gasoline displacer. Since ethanol has about 81 percent of the energy requirement of MTBE, the additional volume of fuel needed is less when ethanol is substituted for MTBE on an equal volume basis. When ethanol is substituted for MTBE to achieve an equivalent oxygen content, the BTU content of the ethanol and MTBE blends are about the same and thus the volume of fuel required is about the same, i.e., there is no ethanol volume penalty.

The economic value of ethanol used in gasoline blends can be determined in several ways. The ORNL-RYM approach described below determines an optimized ethanol or ETBE blend. ETBE

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[14]Hadder, G.R., *Draft Ethanol Demand in Gasoline Production*, ORNL-6926, Oak Ridge National Laboratory, November 1998

blending, like MTBE blending is done in the refinery, where complex mathematical optimization programs are used to minimize refinery costs. Most ethanol is splash blended at terminals near retail distribution points, and at the present time, a refinery may or may not produce an optimal subgrade gasoline for ethanol blending. If the ethanol industry grows, competitive pressures will force refiners to produce optimal subgrade gasolines. This is the approach taken in the ORNL-RYM analysis, which is intended to assess ethanol demand in a growing and robust industry.

If optimal subgrade gasolines are not used for blending, the value of ethanol can be determined from market conditions by equating the profit from an ethanol blend with the profit from the type of gasoline being displaced. The profit, of course, is the difference between the selling price of the gasoline and its cost. In conventional gasoline, ethanol is valued primarily for its octane boost. As an example, ethanol may be blended with regular gasoline to produce a mid-grade blend. The profit for mid-grade gasoline is its selling price less its cost. The profit on a mid-grade ethanol blend is its selling price less the cost of the regular gasoline portion less the ethanol handling charges less the price of ethanol. All prices, except the price of ethanol, are known, and the price of ethanol can now be solved for. The selling price of the mid-grade straight gasoline may differ from the selling price of the mid-grade ethanol blend. In theory, the price of the ethanol blend should be lower, since it has less BTUs than the pure gasoline alternative. However, the difference is small and consumers in general may not be aware of the small milage penalty and the market prices may not faithfully represent the BTU difference. The distinction, however, is not important when actual market prices have been established.

If ethanol is used in oxygenated gasoline or RFG, the ethanol blend must be compared with an MTBE blend. Both oxygen content and octane boost are important here, but the methodology to evaluate ethanol is the same as described above. For summer RFG, RVP constraints must be taken into account and ethanol must be blended with a low-RVP subgrade gasoline. Because VOC restrictions are not limiting for winter gasoline, RVP constraints for ethanol blends are primarily a summertime problem.

In the methodology described above, the value of the gasoline used in the ethanol blend is key. If an optimal subgrade gasoline is used the value of ethanol is similar to the value obtained in the ORNL-RYM analysis. If a less-than-optimal blending gasoline is used, the market ethanol value will be less. There is a subtle technicality here that can cause a little confusion. The ORNL-RYM analysis determines the minimal cost of producing all types of gasolines, including ethanol blends, to meet refinery gasoline target goals. In theory, it may be possible to produce a cheaper subgrade gasoline for ethanol blending at the expense of other gasoline types. Such a solution would produce a higher overall refinery cost and, for that reason, would not be defensible.

Current Ethanol Consumption

Almost all fuel ethanol currently used in the U.S. is in the form of gasohol, or gasoline blends of 10 percent ethanol or less. The Department of Transportation (DOT) estimates the amount of ethanol

used in gasohol from gasohol tax collections, refunds, and credits reported to the Internal Revenue Service, U.S. Department of the Treasury. Blends of less than 10 percent, i.e. E7.7 and E5.5, are chiefly used to meet the requirements for oxygenated fuel to reduce winter carbon monoxide. E10 may be also used to meet the requirements for oxygenated fuel to reduce winter carbon monoxide. Table 14 summarizes consumption by PADD for 1996, the latest year for which data are available.

Table 14. Ethanol and Gasohol Consumption by PADD for 1996
(1000 gallons)

PADD	Total Ethanol	Percent of Total Ethanol	E10	E7.7 & E5.5
1 (East)	192,884	17.87%	1,399,693	687,186
2 (Midwest)	621,748	57.59%	5,562,731	850,311
3 (Southwest)	41,058	3.80%	367,439	56,029
4 (Northwest)	73,719	6.83%	324,494	535,965
5 (West)	150,111	13.91%	166,855	2,174,760
Grand Total	1,079,520	100.00%	7,821,212	4,304,251

Source: Federal Highway Administration, "Monthly Motor Fuel Reported by States", February 1998

Most of the ethanol consumption is in the Midwest, where most of the ethanol is produced and where additional state incentives exist. The second largest consumer region is the East, where much of the ethanol is used to meet winter oxygenated fuel requirements. Ethanol was used as an oxygenate in California as of 1996, but as noted in Chapter 3, new oxygen restrictions adopted in California have virtually eliminated ethanol from the blend market. Consequently ethanol consumption for the Western region will likely decline in the near future.

The Oak Ridge National Laboratory Refinery Yield Model (ORNL-RYM)

ORNL-RYM is an enhanced personal computer version of the Refinery Yield Model of the DOE Refinery Evaluation Modeling System. ORNL-RYM has been extensively peer reviewed by refinery industry experts, and many of the review recommendations have been incorporated into the model. ORNL-RYM is a linear program that includes 50 refining processes, which fall within three general categories:

- C Separation – e.g., crude oil is separated into fractions by distillation
- C Conversion – e.g., molecules are cracked, combined, rearranged
- C Blending – separated and converted streams are mixed to make products that satisfy numerous quality specifications.

The refining processes in ORNL-RYM can be used to produce 40 different products from more than 100 crude oils. Ethanol can be used directly as a blendstock or indirectly as component of ETBE. A

capital investment module provides for the addition of processing capacity.   Modeled gasolines satisfy specifications for:

  C   Octane
  C   Reid vapor pressure (RVP)
  C   Oxygen content
  C   Sulfur
  C   Benzene
  C   Aromatics
  C   Total olefins
  C   Distillation points
  C   Pollutant emissions

The model blends gasolines to satisfy formula and pollutant emission standards mandated by the Clean Air Act Amendments and described by the U.S. Environmental Protection Agency (EPA) Complex Model, which predicts pollutant emissions in terms of gasoline properties. Chapter 3 presented the gasoline specifications for both Federal and California Phase 2 RFG and winter oxygenated fuel requirements. California RFG has stricter requirements than federal RFG and is modeled in separate ORNL-RYM runs.

For analytical purposes dealing with regional oil issues, the U.S. is broken down into Petroleum Administration for Defense Districts (PADDs).   The PADDs are defined as:

  PADD I   - East Coast
  PADD II   - Midwest
  PADD III   - Gulf Coast
  PADD IV   - Rocky Mountains
  PADD V   - West Coast

Premises and Data Sources for ORNL-RYM Runs

For the ethanol demand study, ORNL-RYM represents production of gasoline and other refined products in the year 2010. The year 2010 was selected to coincide with the commercialization goals established for the DOE's cellulosic ethanol evolution program. Data for the ORNL-RYM analyses are obtained from information published by DOE, the National Petroleum Council, the National Petroleum Refiners Association, the California Air Resources Board, and industry journals. Data on energy markets, such as gasoline demand and average petroleum prices (Table 15) , are based on projections published in EIA's Annual Energy Outlook (AEO)[15]. Because significant changes can occur in the

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[15]*Annual Energy Outlook 1996*, DOE/EIA 0383(96), January 1997, U.S. Department of Energy(DOE) / Energy Information Administration (EIA), Washington D.C.

outlook for oil prices and the supply of refined products from year to year, sensitivity runs were made to examine the impact of these changes on ethanol demand. Ethanol demand curves in five-year increments from 2000 to 2025 were derived by using AEO economic parameters to extrapolate the year 2010 demand curve.

Table 15. AEO 1996 Oil Prices and Gasoline Demand

	Reference Case	Higher Ethanol Demand Case
World Oil Price in 2010 (1996 dollars)	$24.77	$34.08
U.S. Motor Gasoline Demand (MMBD)	8.64	8.41
U.S. Motor Gasoline Production (MMBD)	7.94	8.19

Individual ORNL-RYM runs are made for summertime and wintertime conditions for PADDs I, II, III, and V (California only) for the AEO reference projection. This covers about 90 percent of the U.S. refinery capacity in the reference case analysis. Four gasoline types are modeled: conventional gasoline with ethanol, conventional gasoline with ethers, RFG with ethanol, and RFG with ethers. The properties of wintertime RFG are weighted to include winter oxygenated gasoline requirements for carbon monoxide nonattainment areas. The percentage of RFG varies regionally, and this is taken into account in the ORNL-RYM analysis. An annual demand curve for each PADD is derived by combining the summer and winter demand curves. Finally, a demand curve for the entire U.S. is derived by scaling the results up according to the national shares of different gasoline types. The national RFG percentage of the gasoline pool is assumed to be 30 percent. Sensitivity cases examine the impact of different RFG percentages.

The ORNL-RYM analysis assumes that gasoline blending is optimized, with minimum giveaway of gasoline quality. Modeled refineries can produce subgrade gasolines for shipment to blenders, who add optimal volumes of ethanol to produce finished gasoline. The ethanol price to the refinery is net of any tax incentives. Ethanol handling and logistics costs in refining/blending are assumed to be $0.10 per gallon and are in addition to the price of ethanol to the refinery. For each ORNL-RYM run the refinery sees a single price for ethanol which is PADD and seasonal specific. That is regional variations in ethanol prices due to transportation-specific costs and the broad array of state tax incentives is not modeled. Consumers are assumed to be indifferent to ethanol blends, neither seeking nor avoiding these gasolines.

Use of Ethanol in Different Gasoline Types

Depending on the type of gasoline, Clean Air Act and California RFG requirements present advantages and disadvantages for ethanol blending. For example:

1.   Phase 2 RFG for summer ozone nonattainment areas must contain oxygen and compared with conventional gasoline is more costly to make. Both factors seem to present an opportunity for ethanol. However, RFG must have reduced emissions of volatile organic compounds (VOC), and satisfying VOC requirements with high-RVP ethanol blends can be difficult. Ethers like ETBE and MTBE have the advantage lower RVP blending values. For ethanol, there is a cost tradeoff of producing a lower RVP subgrade gasoline to compensate for the RVP increase of the ethanol blend versus the additional processing costs for ETBE. The ORNL-RYM analysis determined that for summer RFG, ETBE blends were generally less expensive to produce than ethanol blends.

2.   Gasoline for winter carbon monoxide nonattainment areas must contain oxygen. Because this is a wintertime gasoline, there is no VOC requirement. As a result, ethanol blends are not disadvantaged by RVP requirements and are generally less expensive to produce than ETBE blends.

3.   Conventional gasolines must have no increase in pollutant emissions relative to a base year. Compared to RFG, satisfying VOC specifications for conventional gasoline is easier, and consequently higher RVP limits are allowed for conventional gasoline. In addition, volatility problems are further mitigated by a 1 psi waiver for RVP in conventional gasoline containing 10 percent ethanol.

To determine the impact of RFG percentages on ethanol demand, ORNL-RYM was used to examine various RFG penetration scenarios. The analysis determined that ethanol penetration decreases as the RFG share of the gasoline pool increases. For summer RFG, the higher cost of RFG compared with gasoline was insufficient to compensate for the extra costs of producing ETBE. For a give ethanol price level and volume of gasoline, the demand for ethanol in conventional gasoline was greater than the demand for ethanol/ETBE in RFG. Use of ETBE further dampens the maximum ethanol demand (i.e., the demand at low ethanol prices) because ether blends are limited to 2.7 weight-percent oxygen versus a 3.5 percent limit for ethanol blends. This corresponds to 7.7 percent versus 10 percent ethanol content, by volume.

Winter RFG requirements can present an opportunity for ethanol, since ethanol blends are not constrained by VOC limits. The ORNL-RYM analysis showed that ethanol blends were generally used in both RFG and conventional gasoline in the winter season. The analysis concluded that because of the oxygen requirements of RFG, more ethanol was used in the wintertime with higher RFG percentages.

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Figure 2 Ethanol Demand Curve for U.S. Gasoline Production and Finishing in Year 2010
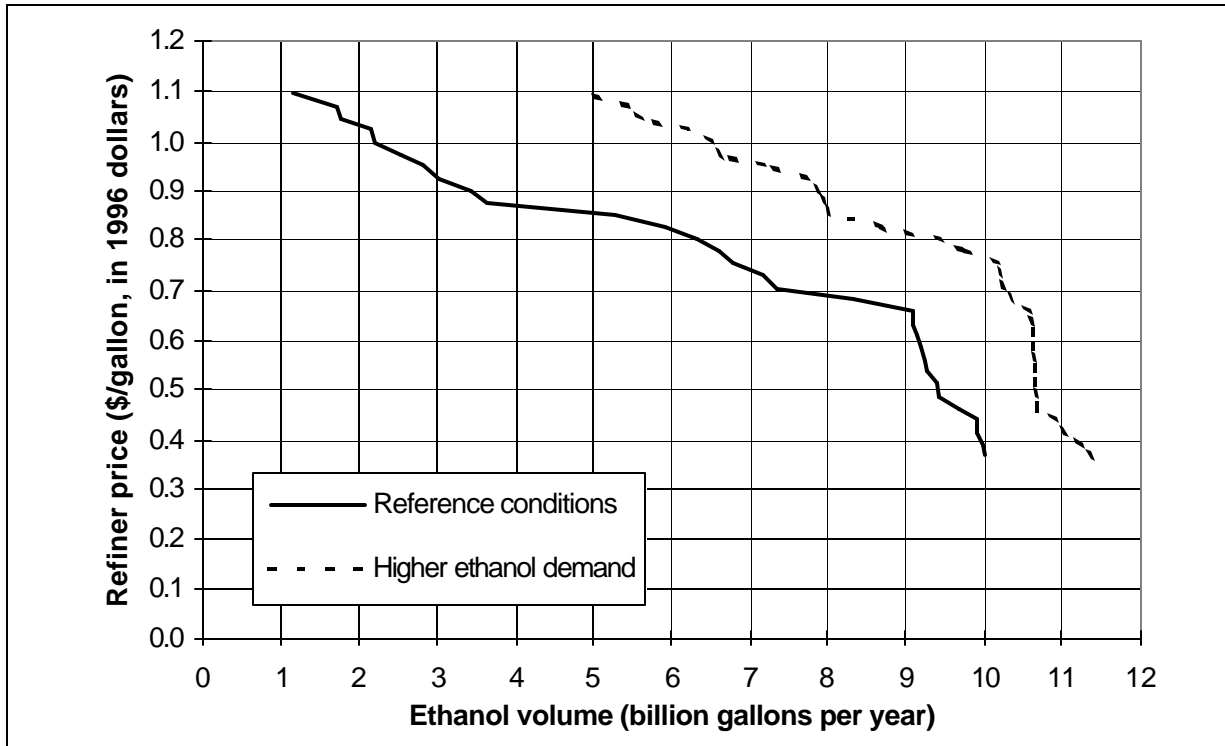
Because RFG opt-in cannot be varied seasonally, there is a trade off when considering higher RFG percentages between the dampening effect on ethanol demand of summertime RFG and the amplifying effect of wintertime RFG. When these two factors are combined, the ORNL-RYM analysis concluded that ethanol demand is lower with a higher share of RFG in the gasoline pool.

Ethanol Demand

Figure 2 shows demand for ethanol as a function of price of ethanol to the refinery for both the reference and higher ethanol demand conditions, which correspond to the reference-case and higher-economic-growth AEO projections, respectively. Figure 3 displays ethanol demand curves for the years 2000 to 2025 in five-year increments for the reference conditions. Ethanol demand for reference conditions in year 2010 is 2 billion gallons per year (BGY) at a refiner price of $1.00 per gallon (1996 dollars) and 9 BGY at a refiner price of $0.67 per gallon. For higher ethanol demand conditions (e.g., higher oil prices and gasoline demand) shown in Figure 2, ethanol demand is 6.5 BGY at a refiner price of $1.00 per gallon, and 10 BGY at a refiner price of $0.77 per gallon of ethanol. The refiner price of ethanol is the highest price (after credit for subsidies) that an ethanol producer can command at the refinery/blender gate, as determined by ethanol's value as an ether feedstock or by the refining values

of the gasoline blendstocks it displaces. Costs incurred by the refiner for ethanol blending and handling
are not included in the price the refiner pays for ethanol.

Figure 3. Ethanol Demand Curves for U.S. Gasoline Production and Finishing in Years 2000 to 2025 - Reference Conditions
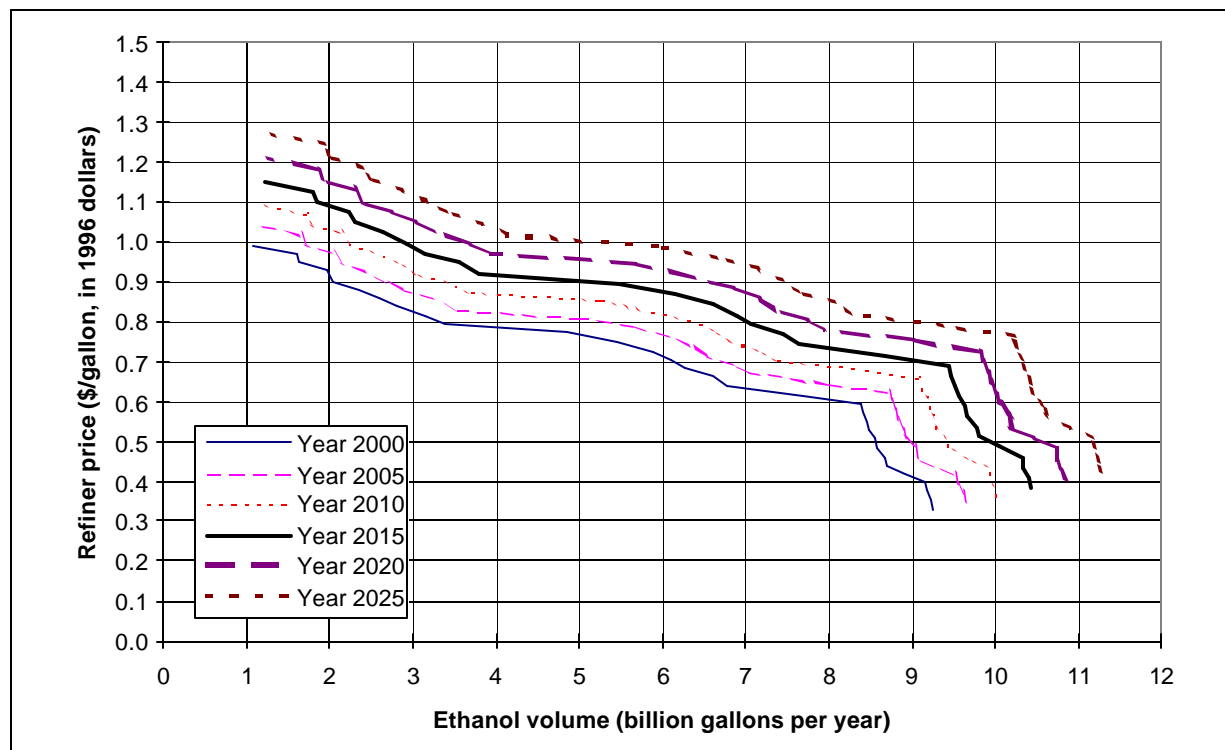
The ethanol demand curves exhibit a range where the ethanol demand is elastic followed by a range where the demand is inelastic. For the reference conditions, the dividing point is 9 BGY or $0.67 per gallon. As the price of ethanol drops from $1.10 to $0.67, ethanol displaces more expensive components of gasoline and its use produces a reduction in the overall refinery cost of producing a target BTU-product slate. At an ethanol price of $0.67, most of the benefit from displacing more expensive components has been achieved and the amount of ethanol used is abutting upon regulatory limits. Consequently, there is little additional refinery savings from using more ethanol.

For regions outside of California, future summer ethanol demand is dominated by conventional gasoline because (1) limits on emissions of VOCs make summer RFG difficult to produce with oxygenates like ethanol that produce high-RVP blends and (2) ethanol's attractiveness in conventional gasoline is enhanced by the 1 psi RVP waiver for 10 percent ethanol blends. Ethanol demand is relatively greater in PADD II (Midwest) and PADD III (Gulf Coast) because of their relatively large volume of conventional gasoline and small share of RFG production.

In California, the RFG production share is 87 percent of the gasoline pool; thus, future summer ethanol demand is dominated by ETBE and ethanol blended to RFG. Relatively less ethanol is used in

Figure 4 Ethanol Demand Sensitivity to MTBE Price for PADD III Gasoline Production and Finishing Year 2010 Summer - Higher Ethanol Demand
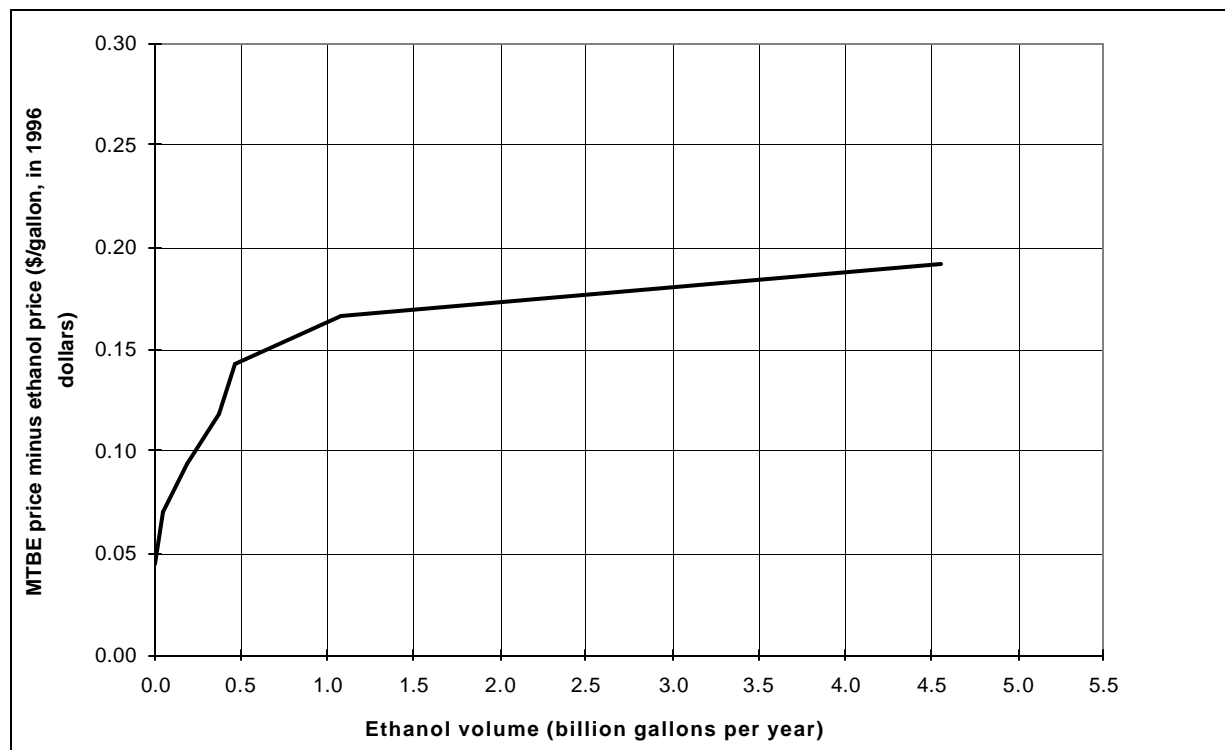
conventional gasoline because the RFG production share is very high. During the winter, there is a significant increase in use of ethanol in RFG, as ethanol displaces lower-RVP ETBE.

MTBE and Ethanol Price Differences

Ethanol and MTBE, the two oxygenates most commonly used today, compete primarily on price. Figure 4 shows how the volume of ethanol used varies according to the price difference between MTBE and ethanol for PADD III higher ethanol demand summer conditions. The RFG production share in PADD III is 18 percent. When the MTBE costs 4 cents (1996 dollars) per gallon more than ethanol, no ethanol is used and MTBE provides virtually all oxygen requirements. When MTBE costs 19 per gallon more than ethanol, ethanol usage is at a maximum. The demand for ethanol is very elastic when the price difference between MTBE and ethanol is in the 17 to 19 cents per gallon range; the ethanol demand increases from 1.0 to 4.5 BGY over this 2 cents per gallon range.

For comparison with the summer 1977 market conditions, the spot price difference between MTBE and ethanol in PADD III ranged from 13 to 23 cents per gallon with an average difference of about 19 cents per gallon[16].

Gasoline Specification Changes

Changes in gasoline specifications could result in higher ethanol demand. Sensitivity cases suggest that ethanol demand could increase with specification changes for (lower) sulfur content, (higher) oxygen content, (higher) VOC emissions, and (higher) octane number. Significant increases in ethanol demand could occur for reduced sulfur gasoline and higher octane requirements. A VOC waiver for ethanol used in RFG increases ethanol's attractiveness. Increasing the allowable oxygen limit in gasoline could increase the demand for ethanol by up to 16 percent. Accounting for toxic air pollutants associated with MTBE in EPA's Complex Model has virtually no effect on ethanol demand.

Sulfur Reduction in Gasoline

The Environmental Protection Agency believes that reduction of sulfur in gasoline may be required to enable use of advanced vehicle pollution control technologies. Summer ethanol demand was estimated for PADD II (Midwest), with production of 100 percent low sulfur gasoline (LSG) with a sulfur content of 100 parts per million. ORNL-RYM shows that a requirement for LSG substantially increases the demand for ethanol over a significant refiner-price range of for ethanol. The ethanol demand increase is due, in part, to benefits of ethanol in sulfur reduction through dilution. In conventional hydrocarbon processing, there is a loss of octane in the reduction of sulfur (through saturation of olefins), and the ethanol demand increase is related to octane recovery. Ethanol demand should increase with a LSG program – the ethanol demand increase will be greater with larger LSG program coverage and with more stringent sulfur specifications.

Oxygen Content

While the maximum allowable oxygen content for gasoline is currently 3.5 weight percent for ethanol blends (about 10 percent ethanol by volume), it has been reported that modern vehicles can perform adequately with oxygen levels of up to 6 weight percent (about 17 percent ethanol by volume). To evaluate its sensitivity to the oxygen specification for gasoline, ethanol demand in PADD II (Midwest) has been estimated in summer and winter cases with maximum allowable oxygen content of 6 weight percent. With the revised oxygen specification, ethanol demand increases by as much as 16 percent. Follow-up consideration of any gasoline quality change, including a change in the oxygen specification, would rely on guidance of both automakers and refiners. Automakers have expressed concerns about ethanol's potential adverse effects on driveability and air/fuel control.

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[16]Oxy-Fuels News Price Report, Oxy-Fuel News, Vol. X, No.23, 1998, Hart/RI Fuel Information Services, Arlington, VA

Octane Number

The likelihood of an increase in gasoline's octane specification is uncertain, but nonetheless plausible. For example, higher compression ratios may be needed to achieve higher efficiencies. At higher compression ratios, higher octane gasolines might be needed to inhibit preignition. With a blending octane number that is substantially higher than the gasoline pool specification, ethanol is a very significant source of octane numbers. There is a correspondingly significant increase in ethanol demand when the octane specification for gasoline has been increased by 1 number.

Volatile Organic Compounds

Limitations on VOC emissions make summer RFG difficult to produce with high RVP oxygenates like ethanol, and proponents of ethanol use in RFG have sought relief from the current VOC specification. A sensitivity case study examined the impact of an ethanol-based RFG waiver which allows a 5 percent increase in the specification for VOC emissions. This waiver decreases the VOC advantage of MTBE-based RFG. There is an ethanol demand increase with the VOC waiver in PADD II (Midwest). However, this increase is muted by the fact that only 11 percent of gasoline produced in PADD II gasoline is RFG. The nationwide effect of the waiver could be a significant increase in ethanol demand with an RFG production share of 30 percent - the national average. As noted in Chapter 3, the National Academy of Science is in the process of studying the impact of an RVP waiver for ethanol-RFG blends on ozone formation and California recently released a report recommending against an RVP waiver.

Toxic Air Pollutants

The EPA Complex Model for emissions of pollutants does not account for TAP emissions associated with evaporative and exhaust emissions of MTBE. If TAP due to MTBE were taken into account, ethanol could have an additional advantage in blending. In a sensitivity case, the TAP specification for ethanol-containing RFG has been increased by the benzene-equivalent toxicity due to MTBE, which is accounted for in the EPA Complex Model. However, the TAP correction has virtually no effect on ethanol demand in PADD II(Midwest).

5. Neat Fuels

The term neat fuel, as used in this document, applies to mixtures of gasoline and ethanol that contain at least 85 percent ethanol by volume. In the United States, ethanol must contain a minimum 5 percent denaturant by law, and E85 and E95 are the most commonly used blends. E85 is currently the blend of choice for light-duty vehicles, flex-fueled vehicles (FFV), while E95 is intended for use primarily in heavy-duty vehicles, if the technology is successfully developed. E70, although not classified as a neat fuel, is sometimes used in cold weather to improve vehicle startability. It is anticipated that if a neat fuel market does successfully evolve, E85 will be the predominant blend in the light duty vehicle market. The term E85 is used here interchangeably with neat fuel and the reader should interpret it as encompassing all neat ethanol fuel mixtures.

Since ethanol is more valuable when used in low-level gasoline blends than in neat fuels, the development of a significant neat ethanol fuel market will likely evolve only after the blend market is somewhat saturated. Low-level blends also have the advantage that they can be used without modifications to existing automobiles and can be dispensed through the normal retail gasoline distribution system, while neat fuels require infrastructure changes.

For neat ethanol fuels to penetrate the market three things must happen: (1) the price of E85 must be competitive with gasoline on gasoline-gallon equivalent basis, (2) E85-capable cars must be available, and (3) a reliable retail supply of E85 must be available. This section explores what the price of pure ethanol (E100) must be for E85 to be competitive with gasoline. It does not address the question of market penetration, which must consider the second and third items as well as ethanol production costs, new technology adoption, and infrastructure improvement rates. The availability of E85-capable cars and infrastructure barriers relating to the distribution of ethanol fuels are briefly discussed in this section. More detail is contained in Section 6. Some infrastructure barriers, primarily those related to bulk storage and transportation, apply to ethanol used in low-level blends and in neat fuels. Because ethanol transportation costs will depend on the distance between the end user and the ethanol producing regions, ethanol market penetration will vary from region to region.

Competitive Price for Neat Fuels

Although ethanol has only about two-thirds as many BTUs as gasoline for an equal volume, it has a higher combustion efficiency on a BTU basis. In a recent EPA test (Table 16), a 1998 Ford Taurus FFV achieved a fuel economy using E85 equal to about 74 percent of that of gasoline, in miles per gallon. Adjusting for the 15 percent gasoline portion of the E85 fuel, the pure ethanol fuel economy is about 70 percent of that of gasoline. Since the ratio of the BTU content of ethanol to gasoline is about 66.7 percent, the 70 percent fuel economy ratio represents a BTU efficiency increase of about 5 percent for ethanol, which is in agreement with theoretical engineering calculations. The EPA fuel economy data are summarized below.

Table 16. 1998 Ford Taurus FFV EPA Fuel Economy Measurements			
	E85 MPG	Gasoline MPG	Ratio of E85 MPG to gasoline MPG
City	14.8	19.8	74.75%
Highway	25.0	34.0	73.53%

Several avenues are available to create a consumer demand for E85 and different strategies have to be developed to appeal to the fleet and consumer market. Many fleets are under EPACT or CAAA requirements to use alternative fuels. Here, ethanol competes with other alternative fuels on the basis of cost and special interest considerations. Fleet managers will consider both the cost of the fuels and the incremental costs of the alternative fuel vehicle. Special tax incentives may tilt the decision to a particular vehicle/fuel combination. Fuel availability will also be important, and flexible fueled vehicles may have an advantage over dedicated fuel vehicles in some situations. Special interest considerations may play a pivotal role in the choice of alternative fuels. Some ethanol-producing states have enacted legislation requiring state vehicles to use ethanol when available. Gas and electric utilities will favor their own fuels and may provide incentives for purchase of CNG or electric vehicles.

The consumer market is influenced more by personal choice and marketing campaigns than the fleet market. As gasoline prices in America are low, both historically and relative to many other countries, fuel costs are not a primary consideration in many consumer vehicle choices, as is evidenced by the rising popularity of sport utility vehicles. While some cars with high performance engines require premium gasoline, many consumers purchase it because of a perceived performance benefit or in response to successful product promotion.

Ethanol has a higher octane value than gasoline and when used in a high performance engine can deliver more power – a fact long recognized by many race car drivers who often use alcohol fuels for their extra performance boost.   Properly marketed to the consumer segment, E85 could be promoted as an alternative to premium gasoline, which has historically enjoyed an 18 to 20 cent price advantage over regular gasoline. In the U.S., premium gasolines comprise about 20 percent of all gasoline sales. Since most premium gasoline is used in cars, the percentage is higher for personal vehicles.

A 1997 survey funded by the Governor's Ethanol Coalition looked how at much extra consumers in the Midwest would be willing to pay for ethanol fuels because of their environmental benefits, which were characterized as reducing vehicle pollutants, and their higher octane levels. One-third of the respondents said they would pay more than 10 cents per gallon for a fuel with these features and one-half indicated they would pay 1 to 10 cents more per gallon. The survey did not include questions about the greenhouse gas benefits which would accrue from cellulosic ethanol. The researchers concluded that the messages that should be promoted at this time are environmental benefits and engine performance. They suggested that the messages of benefits to national energy security (oil

displacement), benefits to the economy, and lower price would be less efficient until drivers had more core product information about ethanol.

Should E85 compete with regular or premium gasoline? Since E85 is a high-octane fuel, introducing it to the general public as a premium fuel would seem to have several advantages. First, the Governor's Ethanol Coalition's survey suggested that fuel performance was important to consumers. Second, vehicles with high compression engines that require premium fuel are more suited to using ethanol efficiently.

Tables 17 through 20 display what the cost of ethanol should be to compete with gasoline. Separate tables are provided to quantify the value of ethanol compared to premium and average or blend-weighted gasolines. (EIA gasoline price projections are the average of the prices of regular, mid, and premium grades, weighted by their relative consumption.) The following paragraphs explain how the figures presented in the tables were derived.

Table 17. Adjustments to AEO98 Retail Gasoline Price Forecasts to Get Wholesale Price of "Average Gasoline" (1996 cents per gallon)						
Year	1996	2000	2005	2010	2015	2020
Motor Gasoline Price (EIA average)	122.5	121.2	124.7	126.0	126.6	126.8
Taxes	44.0	39.1	33.7	29.1	25.1	21.6
User Cost Without Taxes	78.5	82.1	90.9	97.0	101.5	105.1
Dealer Markup	9.0	9.0	9.0	9.0	9.0	9.0
Wholesale Price of Gasoline plus Transportation Cost (P1)	69.8	73.1	81.9	88.0	92.5	96.1

Note: In EIA's Annual Energy Outlook, the gasoline price is a weighted average of all grades.

Table 18. Ethanol Price Equivalence and Price Targets In Competition With Premium Gasoline at 13 Cents More Per Gallon Than "Average Gasoline"

(1996 cents per gallon)

Year	1996	2000	2005	2010	2015	2020
Wholesale Price P1 from above	69.8	73.1	81.9	88.0	92.5	96.1
Premium Price Differential	13.0	13.0	13.0	13.0	13.0	13.0
Wholesale Price of Premium Gasoline	82.8	86.1	94.9	101.0	105.5	109.1
E100 Cost Equal to 70% of Premium Cost	58.0	60.3	66.5	70.7	73.8	76.4
Tax Incentive in Constant Dollars	49.4	48.0	39.1	33.7	29.1	25.1
E100 Price Target Equal to E100 Cost Plus Tax Incentive (Supply Price)	107.4	108.3	105.6	104.4	102.9	101.5
Price of E85 Without Incentive	61.7	64.2	70.7	75.2	78.6	81.3
Price of E85 Plus Incentive	103.7	105.0	104.0	103.9	103.3	102.6
Gasoline-Gallon Equivalent Prices						
Price of E85 Without Incentive	82.8	86.1	94.9	101.0	105.5	109.1
Price of E85 Plus Incentive	139.2	140.9	139.5	139.4	138.7	137.8

Note: Wholesale gasoline price P1 is a weighted average of all grades and includes transportation cost.

Table 19. Ethanol Price Equivalence and Price Targets In Competition With Premium Gasoline at 10 Cents More Per Gallon Than "Average Gasoline"

(1996 cents per gallon)

Year	1996	2000	2005	2010	2015	2020
Wholesale Price of Gasoline (P1)	69.8	73.1	81.9	88.0	92.5	96.1
Premium Price Differential	10.0	10.0	10.0	10.0	10.0	10.0
Wholesale Price of Premium Gasoline	79.8	83.1	91.9	98.0	102.5	106.1
E100 Cost Equal to 70% of Premium Cost	55.9	58.2	64.4	68.6	71.7	74.3
Tax Incentive in Constant Dollars	49.4	48.0	39.1	33.7	29.1	25.1
E100 Price Target Equal to E100 Cost Plus Tax Incentive (Supply Price)	105.3	106.2	103.5	102.3	100.8	99.4
Price of E85 Without Incentive	59.5	61.9	68.5	73.0	76.4	79.1
Price of E85 Plus Incentive	101.5	102.7	101.7	101.6	101.1	100.4
Gasoline-Gallon Equivalent Prices						
Price of E85 Without Incentive	79.8	83.1	91.9	98.0	102.5	106.1
Price of E85 Plus Incentive	136.2	137.9	136.5	136.4	135.7	134.8

Note: Wholesale gasoline price P1 is a weighted average of all grades and includes transportation cost.

Table 20. Ethanol Price Equivalence and Price Targets In Competition With "Average Gasoline" (1996 cents per gallon)						
Year	1996	2000	2005	2010	2015	2020
Wholesale Price of Gasoline (P1)	69.8	73.1	81.9	88.0	92.5	96.1
E100 Cost Equal to 70% of Premium Cost	48.9	51.2	57.4	61.6	64.7	67.3
Tax Incentive in Constant Dollars	49.4	48.0	39.1	33.7	29.1	25.1
E100 Price Target equal to E100 Cost Plus Tax Incentive (Supply Price)	98.3	99.2	96.5	95.3	93.8	92.4
Price of E85 Without Incentive	52.0	54.5	61.1	65.5	68.9	71.6
Price of E85 Plus Incentive	94.0	95.3	94.3	94.2	93.6	92.9
Gasoline-Gallon Equivalent Prices						
Price of E85 Without Incentive	69.8	73.1	81.9	88.0	92.5	96.1
Price of E85 Plus Incentive	126.2	127.9	126.5	126.4	125.7	124.8

Note: Wholesale gasoline price P1 is a weighted average of all grades and includes transportation cost.

The gasoline projections are taken from the EIA AEO98 forecasts, which are expressed in 1996 dollars. EIA assumed the gasoline taxes do not change in nominal dollars throughout the forecast period, and consequently they decrease in constant dollars (as a result of inflation). The fuel taxes were backed out of the EIA projections to get the actual gas price trends, which were masked by the decreasing cost of the fuel taxes in constant dollars. Using the 1996 Annual Energy Review (AER), motor fuel taxes were estimated at 44 cents per gallon, and then deflated by the 3 percent GDP inflator used for the AEO forecast.

According to the AER, the difference between the wholesale and retail (without taxes) prices of gasoline is about 12 cents. This agrees with various industry estimates of 9 cents per gallon for dealer markup and 3 cents per gallon for transportation. Since the Office of Fuels Development's estimates of ethanol supply prices are wholesale prices plus transportation costs, the gasoline prices were adjusted for the 9-cent dealer markup, but not for the 3-cent transportation costs

The AEO gasoline price projections are a weighted average of all grades. The AER reports that, the difference between premium and the blend-weighted gasolines is about 10 cents per gallon at the wholesale level and 13 cents per gallon at the retail level. To bracket this range, two tables showing the calculation of an equivalent price of ethanol compared with the price of premium gasoline are presented. As noted above, the difference between premium and regular is higher, about 18 to 20 cents per gallon at the retail level. This shows the willingness of consumers to pay more for certain types of fuels.

After getting the wholesale price of gasoline plus transportation costs, the price of a gallon of ethanol (E100) is set to 70 percent of the gasoline cost to account for the difference in miles per gallons. The ethanol supply prices (including transportation) needed for competitiveness with gasoline are

determined by adding the value of the Federal tax incentives in constant dollars. The tax incentive is assumed to be renewed at a nominal 51 cents per gallon in 2007.   If the tax incentive is decreased, the supply target prices shown in the tables will be less. The E100 cost is equal to 70 percent of the cost of gasoline and provides a lower bound for the ethanol supply price.

The tables also display competitive E85 prices on a per gallon and a gasoline-gallon equivalence basis, with and without the tax incentive. The price of E85 is determined by a mixture of 85 percent ethanol and 15 percent gasoline. In the premium-gasoline cases, the price of premium gasoline is used even though using regular as a mixture may be sufficient due the higher octane rating of ethanol. This adds a penny or two per gallon.

The tax incentive for neat fuel comes primarily from the income tax credit. As noted earlier, the income tax credit is limited by the taxpayers tax liability and is more difficult to administer than the excise tax exemption. Consequently, some taxpayers may not be able to fully utilize the income tax credit and this could be an impediment to E85 market penetration. Another important consideration is that the tax incentives are typically extended for periods of 10 years or less, which introduces uncertainty for ethanol suppliers, especially during the last few years before the incentives expire.

Neither state and other Federal incentives nor regionally dependent ethanol transportation charges are considered here. These factors must be incorporated into supply cost estimates. Alternative vehicle incentives are discussed below. They may be very important for buyers who look at total cost of ownership, i.e., cost of vehicle plus cost of fuel.

It must be emphasized that the ethanol supply prices are the prices that make ethanol and gasoline economically equivalent. They are one of several factors that can be used to establish ethanol supply cost targets. A much more detailed analysis is needed to determine whether E85 will penetrate the marketplace.

E85-Capable Vehicles

The widespread availability of vehicles that can use neat ethanol fuels is one prerequisite for neat fuel to penetrate the market. At the present time, all the major U.S. automobile manufactures have introduced flexible-fueled vehicles that can use either gasoline or E85. The manufactures are currently motivated by the CAFE credits granted under AMFA. The incremental cost of an E85 FFV is almost insignificant, e.g., $165 for the Ford Taurus. The experience in Brazil has shown that automobile manufacturers can easily gear up production of these vehicles to satisfy consumer demand.

Under EPACT, purchasers of alternative-fueled vehicles are entitled to a $2000 tax deduction. The value of this deduction depends on the purchaser's marginal tax bracket – for a 28 percent tax bracket, it is worth $560, for a 35 percent tax bracket, it is worth $700. For these two tax brackets, the purchaser would benefit by $395 or $535 by purchasing the FFV Ford Taurus. Assuming the

purchaser drives the car for 78,000 miles (about 6 years at the national average of about 13,000 miles per year), the purchaser would use 3,250 gallons of gas, based on 24 miles per gallon. The 24 miles per gallon assumption is based on a 60 percent city and 40 percent highway driving pattern, using the Taurus fuel economy statistics given in Table 16. The two tax deductions, after adjusting for FFV cost differential, are worth 12 or 16 cents per gallon of gasoline, respectively, ignoring the additional benefit of the cost of money. If E85 were used instead of gasoline, the purchaser would use 4390 gallons of E85 and the adjusted tax benefit would be worth 9 or 12 cents per gallon of E85.

Interestingly, the purchaser of the Taurus FFV can use either gasoline or E85, and so a purchase of the FFV over the conventional Taurus would be beneficial in all circumstances. (Not all AFVs have a flex-fuel capability.) This is characteristic of the current dilemma that FFV operators are not using alternative fuels, a situation exacerbated by fuel availability issues. However, the introduction of FFVs into the vehicle fleet is a first step to solving the chicken or the egg conundrum associated with alternative fuels, i.e., which should come first, the alternative-fuel vehicles or the alternative fuel?

For fleet managers, who are required to use alternative fuels in their vehicles, the EPACT tax deductions are an important consideration is determining vehicle purchases. The vehicle incentives can be used to offset the incremental cost of the alternative fuel.

Refueling Facilities

A major infrastructure barrier for neat fuel is the availability of neat fuel refueling facilities. Refueling stations will have to be outfitted with separate distribution and dispensing equipment. Currently, there is only a handful of stations that dispense E85, most of which are concentrated in the Midwest near ethanol production plants. Plans to increase the availability of E85 refueling stations in the Midwest states are on the drawing board. If a sizable neat ethanol market does materialize, infrastructure considerations will dictate that it will evolve first in and around ethanol producing regions.

E85 Demand

This section presents a gasoline price equivalence for E85, but not a demand curve similar to the demand curve developed by ORNL for low-level ethanol blends. EE is in the process of developing an analytical capability to estimate potential E85 penetration as a function of supply price plus tax incentives. This is an evolutionary effort and the current crop of models do not sufficiently capture the range of market effects needed to credibly model E85 penetration.

EIA performs independent analyses that are widely accepted by the public, and their E85 projections in the AEO98 are summarized here. EIA projects E85 usage will increase by 20.5 percent per year through 2020. The E85 usage in 1997 of 0.0012 quadrillion BTU is projected to increase to 0.0032, 0.0749, and 0.1332 quadrillion BTU in 2000, 2010, and 2010, respectively. EIA projects alcohol-

fueled vehicles will make up 10 percent of the dedicated AFVs and 26 percent of the flex-fuel AFVs (Table 21). (Note: .076 quad = 1 billion gallons of ethanol.)

Table 21. EIA Projections of Ethanol used in E85

Year	Quadrillion BTU	Billion gallons
1997	0.0012	0.016
2000	0.0032	0.042
2010	0.0749	0.985
2020	0.1332	1.753

In the AEO analysis, EIA assumed all ethanol would be derived from corn and the cost structure would remain similar to the current corn-ethanol cost structure. EIA also assumed the ethanol tax incentive would continue at the current nominal level, i.e., at a decreasing rate in real dollars. If ethanol production prices were to decrease, E85 production would be greater.

6. Transportation Logistics and Infrastructure Barriers

Some transportation logistics and infrastructure barriers, primarily distribution and bulk storage, apply to ethanol used as a blendstock or as a neat fuel. Neat fuels require infrastructure additions for fuel dispensing, especially at the retail level and the availability of vehicles that can use neat ethanol.

The major infrastructure issues are summarized below:

       C   Ethanol plants have to be located near feedstock sources.

       C   Ethanol costs for transporting ethanol are more expensive than for gasoline. Thus ethanol plant proximity to the end user is important until an alternative distribution system, e.g., dedicated pipelines, is developed for ethanol.

       C   A network of accessible retail filling stations capable of dispensing neat ethanol must be established.

       C   Vehicles that can use neat ethanol must be readily available.

Proximity to Feedstock Supply

Bulk agricultural feedstock is expensive to transport and consequently most ethanol production facilities will be located near feedstock sources. The Midwest and some central and southern states are the most promising locales for bioenergy feedstocks. Agricultural wastes in states such as California provide additional niche opportunities. ORNL is currently in the process of developing a detailed geographic mapping of potential sites for cellulosic ethanol feedstocks[17].

Transportation Restrictions

Because ethanol and ethanol blends absorb water, they cannot be shipped in existing pipelines unless the pipelines are purged of water. Problems arising from water absorption are discussed below. Another potential problem is that the strong solvent properties of ethanol can dislodging of previously precipitated deposits. The loosened sediment may remain undissolved in the fuel or may be dissolved by the ethanol. In either event, procedures must be adopted to address this possibility.

Consequently, most ethanol is transported by more costly land or barge conveyances to a terminus at or near a retail distribution outlet, where it is splash blended with gasoline. Due to the relatively high

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[17]Marie E. Walsh, Robert L. Perlack, Anthony Turhollow, Daniel de la Torre Ugarte, Denny A. Becker, Robin L. Graham, Stephen E. Slinsky, and Daryll E. Ray, "Evolution of the Fuel Ethanol Industry: Feedstock Availability and Price", Draft Document, Oak Ridge National Laboratory, Oak Ridge, TN, October 26, 1998.

ethanol transportation costs, most ethanol usage occurs in the Midwest, where the majority of the ethanol is produced. Both ETBE and MTBE have the advantage that they are refinery products and can be blended with gasoline and transported through existing pipelines without causing water solubility problems. However, the extra costs and the perceived cost risk to convert ethanol to ETBE currently outweigh the savings in ethanol transportation costs.

Water Solubility and Phase Separation

Ethanol is infinitely soluble with water; ethers like MTBE and ETBE have very low solubility, and gasoline has virtually no solubility. The water solubility characteristics of these fuels have very important consequences concerning their use and the precautions that must be taken against water contamination.

Phase separation of gasoline is the separation of gasoline into two parts or phases, a gasoline phase and a water phase. Nonoxygenated gasoline can absorb only very small amounts of water before phase separation occurs. Because water is denser than gasoline, the separated water condenses into a layer beneath the gasoline. Gasolines containing ethers can absorb sightly more water than nonoxygenated gasolines before phase separation occur. The water phase contains small amounts of the ether, but because ethers are relatively insoluble in water, almost all the ether remains in the gasoline phase. Alcohol blends can contain a greater amount of water before phase separation occurs. For example, a 10 percent ethanol blend can absorb between 0.2 and 0.5 percent water, depending on the ambient temperature and aromatic content, without phase separation. For ethanol blends, the separated water phase can contain 60 to 70 percent of the ethanol in the original blend. Additional water intrusion can draw more ethanol from the gasoline phase into the water phase.

As water is frequently found in gasoline pipelines, the pipelines are equipped with periodic wells containing drain plugs. Any water entering the pipeline system accumulates in these wells and is easily drained. Consequently, ethanol and ethanol blends cannot be shipped via pipeline if there is any possibility of water intrusion, which is characteristic of the current operating environment for common carrier pipelines. As the drain wells would contain a mixture of water and alcohol, to would not be possible to drain the water from the system without draining the alcohol. Various solutions have been proposed to remedy this problem, but none have been commercialized so far.

Water intrusion occurs in storage tanks due to non-watertight seals and covers and from condensation. Any separated water will be drawn to the bottom of the tank where it can be drained. If the fuel in the tanks contains ethanol, the separated water would contain ethanol and therefore water tightness is an absolute requirement for tanks stored ethanol or ethanol blends.

Phase separation can cause several problems for vehicle operability. The two problems most commonly cited are potential gas line freezing and driveability issues. For gasohol (blends up to10 percent ethanol), the separated water can lead to fuel line freezing. Since the amount of water that can

be absorbed by the gasohol decreases with temperature, a mixture that is saturated at above freezing temperatures may separate at below freezing temperatures. Water condensation in the gas tank can also contribute to phase separation. It is interesting to note that potential gas line freezing can occur with nonoxygenated gasolines for the same reasons. A common solution to this problem has been to add small quantities of alcohol to the fuel tank to dry out the fuel system. This approach takes advantage of the fact that a gasoline alcohol mixture can hold a greater amount of water before phase separation occurs.

Small amounts of water dissolved in gasoline or gasohol do not cause engine operability problems. If phase separation occurs, the water or a water-alcohol mixture could be drawn into the engine, and this will cause operability problems. The probability of this happening is high, since fuel is drawn from the bottom of the tank, which is where the water or water-alcohol mixture settles. No engine can operate on water and engines designed to operate on gasoline or low-level ethanol blends will operate poorly, if at all, on ethanol-water blends. Engines designed to operate with neat ethanol can generally tolerate ethanol-water blends containing up to 5 percent water. However, water content may place additional stress on engine components and lead to premature degradation of some elements.

With advanced distillation techniques and suitable handling and storage practices in the U.S., water intrusion in ethanol and ethanol blends has not been a problem. In Brazil, ethanol is not dehydrated to the extent it is in the U.S. and can contain up to 5 percent water. This has not posed any problems for their alcohol-fueled vehicles, which are designed to run on high content ethanol fuels.

State Restrictions on Transporting Subgrade Gasolines

Some states, for example, Georgia places restrictions on the use of subgrade gasolines, which may needed for splash blending with ethanol. While this does not prevent low-level ethanol blends form being used in the state, it does make them less desirable since they must be blended at the refinery or at a terminal outside of the state.

Transportation and Marketing Costs

A 1993 paper by Bechtold and Wilcox examined ethanol transportation and infrastructure issues. The analysis assumed that 8 billion gallons of ethanol would be produced in 2010, with production centered around five geographic regions. Ethanol consumption in blends, E85, and RFG was assumed to be 2.0, 4.4, and 1.6 billion gallons, respectively. The study looked at storage, transportation, and retail distribution issues. For a large ethanol market penetration, the authors suggested dedicated ethanol pipelines would be constructed. They estimated the additional capital costs required for 8 billion gallons of ethanol per year at $2.26 to $2.94 billion, with $1.53 billion for transportation, $0.52 billion for bulk storage, and $0.21 to $0.89 billion for retail refueling stations. Most of the additional capital costs to retrofit refueling station would be incurred for E85.

A large part of the transportation capital costs estimated the in Bechtold and Wilcox paper was for construction a dedicated ethanol pipeline construction. Some engineers have suggested that the potential exists for solving the problem of shipping gasohol via existing pipelines by introducing an additive with a greater affinity than ethanol for absorbing water. (Water is sometimes purposely introduced into gasoline pipelines as a means of controlling pipeline pressure.). If this approach proves to be successful, it could provide significant costs savings for shipping ethanol.

The Bechtold and Wilcox paper concluded that ethanol transportation costs would be about 4 cents per gallon compared to about 3 cents per gallon for gasoline. Current ethanol transportation costs in the Midwest are in that range. However, estimates of ethanol shipped to coastal states range up to 15 cents per gallon, based on truck transport. The Bechtold and Wilcox estimates assumed significant ethanol production in coastal states, which does not appear likely. Unless the pipeline problem is solved, transportation costs can be a major impediment to shipping ethanol long distances.

For comparison, an American Petroleum Institute (API) research report estimated transportation and marketing costs at 21 to 24 cents per gallon of ethanol for an expanded ethanol market[18]. The report did not explain how this estimate was derived.

The recently completed California report examining alternatives to MTBE estimated ethanol transportation charges from the Midwest at 15 cents per gallon of ethanol, which would be transported by rail or truck. The report estimated total costs of transporting ethanol from Brazil, including insurance and port charges, at 23 cents per gallon. (Because the U.S. imposes a 54 cents per gallon tariff on imported ethanol, this option is not attractive, but is presented to illustrate the range of transportation costs). For ethanol produced in California, transportation costs are estimated at 5 cents per gallon of ethanol[19].

Marketing and Retail Costs

While blends are dispensed through the existing gasoline retail distribution system, neat fuels will require a new retail distribution system be established, and this represents a major infrastructure cost. For blends, bulk storage terminals may require one large tank be dedicated to ethanol. The blends can be stored in the existing gasoline storage terminals. Some additional ethanol receiving and handling equipment may be needed. Neat fuels would require the addition of a number of extra storage tanks. In either case, additional storage capacity may have to be added or throughput increased to account for the higher volume of fuel needed because of the lower volumetric energy content of ethanol. The

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[18]The Economics if Gasoline Ethanol Blends, Research Study #045, November 1988, American Petroleum Institute

[19]Supply and Cost of Alternatives to MTBE in Gasoline, California Energy Commission, Staff Report, October 1998, Publication No: P300-98-013

Bechtold and Wilcox paper also assumed that some ethanol transport would be by pipeline. If so, this would be a major infrastructure cost. The authors concluded that the capital costs of a new transportation infrastructure were significantly larger than the capital costs of additional storage and retail infrastructure costs.

E85 Vehicles

The availability of ethanol-capable cars was discussed above. The incremental cost of converting a gasoline-only vehicle into a flex-fuel vehicle is modest, and the CAFE credits available to the manufactures more than compensate for the additional costs. However, the CAFE credits are limited for FFVs and the credits are set to expire in 2004. The flex-fueled vehicles are not optimized for ethanol, but the results of a recent EPA certification for a 1998 model year Ford Taurus FFV are encouraging. They showed a 9% increased fuel efficiency in city and 7% in highway fuel economy for E85 compared to gasoline on a gasoline-gallon equivalent basis. On a per gallon basis, E85 fuel economy relative to gasoline is 74.7% for city and 73.5 percent for highway driving. EPA also determined that the fuel economy for gasoline used in the FFV was similar to the fuel economy of a conventional gasoline engine. These results are in contrast to test conducted by NREL for 1992 and 1993 model year vehicles that showed a the fuel economy for E85 and gasoline were similar on a gasoline-gallon equivalent basis. The 1998 results highlight the progress made by Ford in adapting the Taurus engine to a range of gasoline and ethanol fuels.

An SAE paper[20] that looked at he potential of ethanol fuels estimated that an E85 flex-fueled vehicle could achieve a 6 percent increase in efficiency compared to gasoline, on a BTU basis. The authors came to this conclusion by examining the properties of ethanol that would produce a performance boost. In light of the Ford Taurus FFV fuel economy for E85, this target is clearly achievable and maybe a little low. The paper also estimated that dedicated vehicles optimized for ethanol could achieve a fuel efficiency increase of 13 percent for E85. The additional increase in fuel efficiency would come primarily from the use of high compression engines. (Ethanol has a higher octane rating than gasoline.) Dedicated vehicles, however, would have little general consumer appeal until ethanol fuel availability is sufficiently widespread and reliable. For now, the expectation is that dedicated ethanol vehicles would be used mainly by centrally-fueled vehicle fleet operators. The authors note, the possibility of developing variable compression engines designed to accommodate a variety of fuels. Such engines would provide the benefit of higher efficiency when using ethanol without sacrificing the flexibility of using gasoline. This would be an ideal solution if the incremental costs were modest.

The additional costs to turn a light-duty vehicle into a flex-fueled vehicle is about $165 according to informal discussions with automobile manufacturers. Because of the higher solvent properties of ethanol, the materials used in the construction of the fuel tank and fuel lines have to be upgraded, e.g.,

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[20]Sinor, Jerry E.. and Bailey, Brent K., Current and Potential Future Performance of Ethanol Fuels, SAE Technical Paper 939376, March 1-5, 1993, Society of Automotive Engineers, Warrendale, PA..

replacing a steel tank with a stainless steel or possibly a plastic tank with stainless lines. The fuel tank capacity may also be increased to accommodate the lower volumetric energy density of ethanol. Other modifications include hardened valve seat inserts, higher volume fuel flow injectors, increased capacity evaporative canisters, special air/fuel ratio calibrations, and changes to the cylinder head configuration, different and spark plugs. Ford has also added a sensor to the fuel line to measure the alcohol concentration (FFV's can run from 0 to 85% alcohol), which is used by an onboard computer to calibrate the amount of fuel injected into the cylinders and adjust the spark timing. On the other hand, Chrysler has elected to rely on the oxygen sensors in the existing emissions control system to provide feedback and adjust the air/fuel ratio.

The availability of ethanol-capable cars and neat ethanol refueling stations is the classic chicken-and-egg problem. The problem, however, is less acute for ethanol than for other alternative fuels due to the fact that the incremental cost of flex-fueled vehicles is less than two hundred dollars. All major U.S. automobile manufacturers are producing and selling ethanol FFVs.

Oil companies Acceptance

Because ethanol is a blending agent not manufactured at the refinery – most ethanol used in low-level blends is splash blended at bulk terminals – some major oil companies, especially those with large oil field holdings, do not favor the use of ethanol for competitive reasons. Smaller, independent refiners without significant oil field investments have been more favorable to ethanol since its higher octane rating allows them to produce a lower octane subgrade product, which provides a greater yield per barrel. Consequently, there is an advantage to locating an ethanol plant in an area served by smaller refiners that are ethanol friendly.

Ethanol blends require the elimination of water from the delivery system, since ethanol, being a polar molecule absorbs water. This restricts the marketing and distribution of ethanol blends in cases where a company's exchange partners do not accept ethanol blends because of water content in their distribution systems.

ETBE is considered refinery friendly by oil companies, since, like MTBE, it is a refinery product and adds to refinery profit margins.   In addition, ETBE can be shipped in existing gasoline pipeline without any modifications. ETBE is also more suitable for use in RFG than ethanol because of the lower vapor pressure of ETBE blends. However, conversion of ethanol to ETBE involves an additional cost.

Neat ethanol and some other alternative fuels may present a competitive threat to oil companies. National and state mandates requiring the use of alternative fuels may force the oil companies to rethink their strategies and develop plans to participate in the alternative fuels market. The automobile manufactures have already begun to embrace this approach as they view the transition to alternative clean fuels as inevitable.

Brazilian Experience

Facing high imported oil prices and a depressed sugar market in the mid 1970s, the Brazilian government adopted an ambitious program to convert sugar cane into ethanol. The Brazilian experience offers a unique view into market and other aspects of the large-scale introduction of an alternative transportation fuel, especially with regard to overcoming infrastructure barriers. The Brazilian government offered consumer incentives for ethanol-capable cars and provided assurances that ethanol would be reasonably and competitively priced. Car manufacturers responded by making a large number of ethanol-fueled vehicles available to the consumers in a rather short period of time. The first generation of ethanol vehicles had corrosion-related problems due to the fact that the long-term solvent properties of ethanol were not well understood. Once these problems were solved and the Brazilian people saw ethanol as a safe, reliable fuel, market penetration, driven by government support programs was sizable. In essence, the Brazilian experience has provided an opportunity to work out many of the new-technology bugs characteristic of first-generation vehicles.

A GAO report[21] on the Brazilian ethanol experience observed that a stable government commitment, fuel prices competitive with gasoline, assurances of a reliable supply, and modest government vehicle incentives were essential ingredients for the Brazilian people to embrace ethanol fuels. The government instituted a major advertising campaign to promote consumer acceptance of ethanol and offered consumer incentives for purchasing ethanol and ethanol-capable vehicles. The government also capped the price of ethanol at 65 percent of the price of gasoline, but initially held the price of ethanol to 40 percent of the price of gasoline.

By 1989, about 30 percent of the vehicles built in Brazil were designed to run exclusively on ethanol fuel, so reliable availability of ethanol at a competitive price was of paramount importance to the owners of these vehicles. However, an ethanol shortage developed around 1990, and consumer confidence in ethanol waned. The Brazilian government was forced to take action to stabilize the ethanol program and assure supply reliability. Part of the problem was caused by the widespread use of dedicated ethanol vehicles. This is in contrast to the U.S., where consumers will likely embrace flex-fueled, rather than dedicated, ethanol vehicles, if a neat ethanol market evolves. Consequently, fuel supply reliability may be less of an issue in the United States. Nonetheless, the ethanol experience in Brazil highlights the importance of consumer acceptance.

Ethanol usage in Brazil has declined form its peak in the mid to late eighties for several reasons. First, the decrease in world oil prices reduced the pressure on the Brazilian government to subsidize alternative fuels. Second, the world demand for, and hence the price of sugar increased. With high sugar prices, the value of sugar canes when used to make sugar became greater than its value when

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[21]Alternative Fuels, experience in Brazil, Canada, and New Zealand in Using Alternative Motor Fuels, General Accounting Office, GAO/RCED-92-119, MAY 1992

used to make ethanol. Both of the situations had the effect of increasing the relative cost of the government's subsidization programs.

7. Greenhouse Gas Emissions

The prospect for global warming from anthropogenic activities is a growing concern in the international community. The Energy Information Administration (EIA) reported that in 1996 about 35 percent of the carbon dioxide emissions from energy use in the Unites States are attributable to the transportation sector. To reduce greenhouse gas (GHG) emissions from mobile sources, the U.S. Department of Energy (DOE) has instituted programs to promote the development and use of renewable biofuels. Biofuels reduce the net carbon emissions to the atmosphere because the carbon dioxide released during biofuel combustion comes from carbon dioxide withdrawn from the ambient environment during the growth stage of the feedstock plants. Cellulosic ethanol derived from bioenergy crops, wood wastes, and agriculture residues is one of the most promising biofuel technologies on the horizon for reducing GHGs, since the biomass-to-ethanol conversion process is makes extensive use of renewable energy.

Preliminary U.S. Plan for Addressing Climate Change

On October 22, 1997, President Clinton unveiled a preliminary proposal for addressing the climate change problem. This proposal was released prior to the Kyoto conference and no updates have been released since the conference. The proposal outlined three stages for meeting U.S. carbon reduction goals. The first stage is the allocation of R&D funding and tax incentives. The second stage calls for a review and evaluation beginning in 2004 and establishing a market-based permit trading system for carbon, and developing the details of the permit system similar in concept to the one used for acid rain emissions. The third stage calls for meeting binding carbon reduction targets by using domestic and international emissions trading programs.

Kyoto Conference

On December 10, 1997, the KYOTO conference attendees adopted the Protocol to the UN Framework Convention on Climate Change (UNFCCC), which set forth an approach for mitigating the prospect of global warming. After considerable negotiation, the participating countries embraced the concept of establishing country-specific goals for reducing anthropogenic carbon emission from a given base year. The U.S. agreed to a 7 percent reduction by 2008, with further commitments for the period 2008-2012 to be established.

Various gaseous emissions contribute to global warming and the process of deciding which gases to include in the protocol was contentious. All countries agreed on carbon dioxide, methane and nitrous oxide, but some countries, including the U.S., advocated the inclusion of the three ozone-depleting gases CFCs--HFCs, PFCs and SF6. The final accord included all six gases, but assigned a base year of 1990 to the first set of three gases and a base year of 1995 to the second set of three gases. In addition, the final protocol allowed for the inclusion of carbon sinks, such as reforestation.

The United States has not yet formulated a final strategy for meeting the carbon reduction target adopted the Kyoto conference. The U.S. is considering various strategies including increasing the number of R&D programs, enacting tax incentives, imposing a carbon tax, establishing a market-based mechanism for trading carbon emission rights, and setting up a system for emissions reduction credits. Rules and guidelines for the emissions reduction credits have not yet been established by the international community and several proposals are being considered. The Joint Implementation proposal, advocated by the U.S., encompasses a partnership between a developed nation and developing host country for projects that reduce carbon emissions, such as renewable energy power plants, retrofits of existing plant and equipment, and forest management projects. The contributing developed country would obtain carbon reduction credits for contributing know-how, technology, and/or capital.

GHG Benefits of Cellulosic Ethanol

Cellulosic ethanol could play an important role in meeting U.S. carbon reduction goals. Because biomass ethanol is a renewable fuel, the carbon released during combustion comes from the carbon withdrawn from the biosphere during feedstock growth. Consequently, vehicular combustion of biofuels produces zero net carbon dioxide emissions. To properly account for carbon emissions associated with a particular fuel, however, the full fuel cycle must be considered. For biomass ethanol, this includes feedstock production, ethanol conversion, and feedstock and ethanol transportation. In addition, the ethanol conversion process produces other products besides ethanol, and the GHG emissions associated with the co-products have to be accounted for. Cellulosic ethanol produces electricity as a co-product, while corn ethanol produces various farm feed products (both dry and wet milling) and corn syrups and sweeteners (wet milling).

The treatment of GHG emissions associated with ethanol co-products has evolved over time. Both Delucchi and Wang, who have developed the two most widely accepted models for estimating GHG emissions from transportation fuels, currently favor the product displacement approach. In this approach, all GHG emissions associated with the combined ethanol / co-product production process are first allocated to ethanol and then adjusted for the GHG emissions associated with the market products displaced by the co-products. For cellulosic ethanol, the co-product is electricity. The excess electricity generated at the ethanol production plant and sold to outside users displaces electricity that power plants would produce for use by the various entities outside of the plant. Other techniques have also been used to distribute GHG emissions between ethanol and the co-products, such as allocating the GHG emissions of a shared process according to the process energy used to produce the ethanol versus the co-products.

A major difference between cellulosic and corn ethanol conversion processes is that the process power for a cellulosic ethanol plant is derived primarily from the biomass (the lignin in the feedstock), whereas the process power for corn ethanol comes primarily from fossil energy. In addition, cellulosic plants produce excess renewable electricity, which displaces fossil-generated electricity. As such, most of the

energy requirements associated with cellulosic ethanol are derived from renewable sources, and net carbon dioxide releases are practically zero.

Recent estimates by Michael Wang show the use of cellulosic ethanol reduces GHG emissions by 80 to 100 percent compared with RFG, on an equal energy basis. Most of the variance is accounted for by the choice of cellulosic feedstock.   Wang also estimates that the use of corn ethanol reduces GHG emissions by 15 to 25 percent compared with RFG. The variance is accounted for by assumptions concerning farm efficiencies, process energy use, and treatment of co-product credits. Among the transportation fuels, cellulosic ethanol provides the greatest GHG benefit, except for methane from landfill gases. However most methane comes from natural gas and the amount from landfills is limited.

Market Related Aspects of GHG Benefits of Cellulosic Ethanol

At the current time, GHG benefits from cellulosic ethanol are strictly an externality. Neither the ethanol producer nor the ethanol user faces any economic or regulatory incentives related to GHG emissions. However, GHG benefits do influence government policy and funding decisions, such as allocation of R&D funds to improve renewable ethanol production technology and reduce costs. They may also play a role in determining ethanol and alternative vehicle tax incentives.

DOE has sponsored an number of studies to examine potential approaches for meeting carbon emission goals in the transportation sector. The studies considered various alternatives, such as enacting tax incentives, imposing carbon taxes, and establishing prescribed carbon release limits through a regulatory mechanism. Since the GHG benefits of ethanol are greater than those of other alternative fuels, the imposition of carbon-related taxes or tax incentives is more favorable to ethanol. However, price and infrastructure developments will eventually determine the extent of ethanol penetration in the marketplace.

Several DOE studies looked specifically at the impact of imposing aggregate GHG emission limits on the transportation sector. Ethanol was the favored alternative fuel in these studies and the market penetration was sizable. The reason for this, as noted above, is that cellulosic ethanol offers the most GHG reduction of all alternative transportation fuels. The studies did not discuss how mandatory carbon emission reductions in the transportation sector would be implemented, and this is a severe shortcoming of these studies.

Several possibilities exist here. In the case of low-blend fuels, ethanol is used as a fuel extender or as a competitor to MTBE. The refinery decision of whether or not to use ethanol is primarily economic – refineries chose the least cost mix of fuel components that will satisfy regulatory requirements. Adding a GHG-related requirement, e.g., as regulatory prescription similar to the way emission standards for criteria pollutants are imposed, is one alternative. Another alternative is to establish a market for buying and selling GHG emission rights, similar to the way emissions rights are traded for certain pollutants in the electricity generation sector.

The neat fuel market presents its own set of challenges. One possibility is to require the sale of a specific number low GHG-emissions vehicles, similar to California's requirements for low emission vehicles (LEV) and zero emission vehicles (ZEV). However, consumer vehicles that use neat ethanol will most likely be flex-fueled vehicles that can operate on either gasoline or ethanol. Consequently, requiring the vehicle mix to contain so many ethanol-capable low-GHG emissions vehicles only gets you half way there, since consumers choose which fuels to use. On the positive side, the incremental cost of an ethanol flex-fueled vehicle is relatively small, less than two hundred dollars. If neat ethanol were available without a significant cost premium, consumers would likely use it, especially if an educational campaign successfully pointed out the environmental benefit. Studies have shown that consumers will pay slightly more for fuels that have a perceived environmental or national security benefit.

Controlling the choice of fuel for vehicle fleets is of course possible, and opportunities exist in this area. As noted in the discussion on EPACT and CAAA fleet requirements, ethanol competes with other alternative fuels. If the government decided to favor ethanol due to its GHG benefits, the government could enact legislation that would encourage the use of ethanol.

Implementing a GHG emissions credit program in the blend market appears feasible since the refineries control the blend mix. Implementing a GHG emissions credit program in the neat fuel market more is more complex, since the neat market is expected to be served by AFVs, and the choice of fuel is at the consumer level.   Any GHG emissions trading program would by necessity have to incorporate a method of measuring emissions, which is not practical for the consumer neat-ethanol market. However, with sufficient record keeping, GHG emissions monitoring, based on fuel usage, could easily be done for vehicle fleets. This could give fleet operators an additional incentive to use ethanol.

The current crop of carbon reduction studies are scoping in nature and do not adequately consider important factors such as technology introduction rates and infrastructure barriers. Despite these shortcomings, the studies do point out that cellulosic ethanol could be an important part of our portfolio of technological solutions for reducing our carbon emissions.

The U.S. favors the implementation of a program for emissions reduction credits, in which developed nations participate with developing host nations on projects that reduce GHG emissions. Cellulosic ethanol can provide tremendous opportunities in this area. For resource-poor countries, cellulosic ethanol projects can reduce a developing country's dependence on imported oil and provide domestic economic growth.   The partner country can reap the benefit of the GHG emissions credits. The opportunity for ethanol production in some developing countries may be even greater than in the U.S. since gasoline prices in many developing countries are much higher.

Estimate of Carbon Reduction for Cellulosic Ethanol

A recent analysis by Argonne National Laboratory concluded that the reductions in GHG emissions for cellulosic ethanol relative to gasoline ranged from about 92 percent for herbaceous biomass to 120

percent for woody biomass[22]. The study assumed conditions applicable to around 2010. The GHG benefits from ethanol were approximately the same whether the ethanol was used in gasohol (E10) or as a neat fuel (E85 and E95).

As a rough estimate, ethanol reduces vehicular carbon emissions compared with the gasoline (on an energy equivalent basis) at the rate of 1.6 tonnes of carbon for each 1000 gallons of ethanol. Various studies have suggested that the value of a ton of carbon avoided is approximately $55. This translates into a GHG benefit of about 9 cents per gallon of ethanol.

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[22]Michael Wang, Chris Saricks, Dan Santini, Fuel Cycle Energy and Greenhouse Gas Emission Effects of Ethanol, Argonne National Laboratory, September 4, 1998